Extending Sutton's "Bounds": A Model of Endogenous Market Structure, Innovation, and Licensing

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Abstract

License agreements constitute between 20-33% of all strategic alliances in sectors commonly identified as likely candidates for an endogenous fixed cost (EFC) model; namely biotechnology and chemicals among others. We develop a model of endogenous market structure and fixed (sunk) cost R&D investment based on Sutton (1998; 2007) and include the ability of firms to license their technology to (potential) competitors. In our model we allow firms with asymmetric R&D costs to offer multiple products differentiated vertically by quality and horizontally by attributes. We also permit firms to pursue license and cross-license agreements as an alternate form of market consolidation which is potentially less costly compared to firm integration via mergers or acquisitions. Thus, our analysis bridges two branches of the industrial organization literature and incorporates strategic alliances into an examination of the relationship between market structure and the intensity of R&D investment. Our results indicate that incorporating the ability of firms to license their technology increases the lower bound to market concentration in R&D-intensive industries relative to the levels that Sutton's capabilities model would predict. In contrast with Sutton's model which predicts a lower bound to R&D intensity that is equivalent to the lower bound to concentration, we find a strictly positive increase in the bounds to R&D intensity relative to concentration when firms are able to license their technology to rivals.

Keywords: *licensing, market structure, technological innovation*

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I. Introduction

The industrial organization literature has long been interested in determining the nature of the relationship between market concentration and technological innovation dating back to Schumpeter (1942). Whereas Schumpeter proposed that more concentrated markets encouraged additional innovation by firms, the empirical relationship between market concentration and R&D intensity, defined respectively as the market share of the industry-leading firms and the ratio of R&D expenditure to sales, remains an open research question. Beginning in the late 1970s, the literature shifted to the development of theoretical models and empirical analyses in which market concentration and R&D intensity were endogenously determined within some equilibrium process.

Within this framework, Sutton (1998; 2007) argues that R&D intensity alone is insufficient to capture all of the relevant aspects of an industry's technology and that a more general "bounds" model which permits a range of possible equilibrium configurations should be considered. However, Sutton's model does not differentiate between forms of consolidation between firms (i.e. licensing and cross-licensing agreements, R&D joint ventures, mergers and acquisitions, etc.) within an industry and the potential impact of these mechanisms upon market structure. Sutton's endogenous fixed cost (EFC) model predicts that in certain R&D-intensive industries, an escalation of fixed (sunk) cost expenditures by existing firms, rather than entry by new firms, will occur in response to exogenous changes in market size or available technology. The EFC model thus implies that there exists a lower "bound" such that as the size of the market increases, market concentration and R&D intensity do not converge to the levels prescribed by perfect competition. If firms engage in licensing and cross-licensing agreements, we cannot determine *a priori* if market concentration and R&D intensity remain bounded away from, or converge to, perfectly competitive levels.

We develop a theoretical model of endogenous market structure and fixed (sunk) R&D investment, based on Sutton (1998; 2007), in which we allow firms to pursue license and cross-license agreements as an alternate form of market consolidation which is potentially less costly compared to firm integration via mergers or acquisitions. Anand and Khanna (2000) find that licensing and cross-licensing agreements are increasingly observed across R&D-intensive industries and constitute between 20-33% of all strategic alliances in sectors commonly identified as likely candidates for a bounds-type model; namely chemicals, biotechnology, and computers and semiconductors. This model adds to the literature on market structure and innovation by allowing for technology licensing, a form of firm consolidation, to be considered within an endogenous framework.

We argue that a firm's R&D investment decision is inseparable from its decision to pursue licensing agreements such that strategic alliances, market structure, and technological innovation are all determined endogenously within some equilibrium process. Moreover, we contribute to the literature on technology licensing by incorporating the decision of firms to both license their innovations and choose their own level of R&D expenditure into an endogenously-determined market structure framework. Our model, in which firms compete vertically in product quality and horizontally in product attributes, provides an alternate framework that complements the existing literature concerning mixed models of vertical and horizontal differentiation (Irmen and Thisse, 1998; Ebina and Shimizu, 2008) and multiproduct competition (Johnson and Myatt, 2006).

In the proposed model, innovating low-cost firms have an incentive to offer licenses to high-cost rivals in order to deter entry by other low-cost firms escalating the market-leading level of quality. This is consistent with Gallini (1984) who finds that incumbent firms have a strategic incentive to license their technology to potential entrants in order to "share" the market and deter more aggressive entry via increased R&D expenditures. Moreover, our model is also consistent with Rockett (1990) who finds that incumbent firms utilize strategic licensing in order to sustain its comparative advantage past the expiration of its patents by facing an industry comprised of "weak" competitors. The model we develop also builds upon the findings of Gallini and Winter (1985) that there exist two contrasting effects of licensing: (i) there is the incentive which successful innovators have to license their technology out to competitors (originally pointed out by Salant (1984) in the comment on Gilbert and Newberry's (1982) preemption model); and (ii) the low-cost firm has an incentive to offer the high-cost firm a license in order to make additional research by the high-cost firm unattractive. Specifically, our EFC model under licensing is largely driven by the second effect which Reinganum (1989) identifies as "minimizing the erosion of the low-cost firm's market share while economizing on development expenditures" (p. 893, 1989).

Within the licensing literature, this analysis is most closely related to that of Arora and Fosfuri (2003) who develop a model of optimal licensing behavior under vertically-related markets. Specifically, they examine the role of licensing as a strategic behavior when multiple holders of a single technology compete not only in a final-stage product market, but also in a first-stage market for technology. Their results indicate that lower transactions costs, arising from stronger patent rights, increase the propensity of firms to license their technology; thereby lowering overall profits to innovators, reducing the incentives to engage in R&D, and decreasing the rates of innovation compared with what would be observed otherwise. Moreover, upon allowing for the number of firms to be endogenously determined, Arora and Fosfuri find that larger fixed costs associated with R&D reduce both the number of incumbent firms as well as the per-firm number of licenses. Our model relaxes some of the assumptions of Arora and Fosfuri such that: (i) competitors in the product market engage in their own R&D activities; (ii) multiple technology trajectories exist within the industry; and (iii) an fully endogenous model for both market structure as well as the level of R&D investment is developed. We further extend the existing licensing literature by providing an alternative explanation to the observance of cross-licensing agreements between competitors; namely as a mechanisms that arises endogenously from complementary technologies across firms.

We draw upon Sutton's (1998) "bounds" model in specifying stability and viability conditions under licensing in order to define the equilibrium configuration of capabilities and determine the lower bound to market concentration when firms are permitted to license their technologies. When firms choose not to license their technologies, the equilibrium configurations and lower bounds to concentration are equivalent to those derived by Sutton (1998) such that his results are embedded within our framework under licensing. However, if firms license their technology to competitors, we find that the set of feasible equilibrium configurations is reduced such that as market size increases, the market share of the quality leader and industry concentration under licensing converge to some lower bound that is greater than the bound derived by Sutton, which is greater than the lower bound under perfect competition. Moreover, for finitely-sized markets, the presence of multiple research trajectories and fixed transactions costs associated with licensing further raise the lower bounds to concentration. Finally, our model implies that R&D intensity is greater under licensing relative to the case without licensing as the innovating firms can recoup additional sunk R&D costs associated with the escalation of quality via licensing to rivals.

The remainder of the essay is organized as follows: in the second section we present the basic framework for the EFC "bounds" model proposed by Sutton (1998; 2007) and discuss our extensions to the model to permit multiple attribute products and technology licensing between rivals; in the third section we define the set of viability and stability conditions which must hold under licensing and derive the feasible equilibrium conditions; in the fourth section we develop the theoretical model and derive the lower bounds to market concentration and R&D intensity that must hold under licensing; and the final section concludes.

II. Theoretical Model: Extending Sutton's Bounds Approach

A. Basic Framework and Notation

Sutton's (1998; 2007) bounds approach to the analysis of market structure and innovation considers firm concentration and R&D intensity to be jointly and endogenously determined in an equilibrium framework. As Van Cayseele (1998) identifies, the bounds approach incorporates several attractive features to the analysis of market structure and sunk cost investments; namely it provides empirically testable hypotheses while permitting a wide class of possible equilibrium configurations consistent with a diverse contingent of game-theoretic models. Thus, we adopt the basic endogenous sunk cost framework proposed by

Sutton (1998) as the basis for our theoretical framework incorporating the ability of firms to license their technology to competitors.

The bounds approach considers firm concentration to be a function of endogenous sunk costs in R&D investment rather than as being deterministically driven by exogenous sunk costs. As the level of firm concentration will affect the incentives to innovate, the endogenous sunk cost framework provides the opportunity for some firms to outspend rivals in R&D and still profitably recover their sunk cost expenditures. The effectiveness with which firms can successfully recoup their sunk cost outlays depends upon demand side linkages across products, the patterns of technology and consumer preferences, and the nature of price competition. Moreover, the model allows for multiple technology holders to viably enter into the product market in equilibrium and successfully regain their sunken investments provided that the market size is sufficiently large.

In building on the framework developed by Sutton (1998), we are interested in examining an industry characterized by a product market consisting of goods differentiated both vertically in observable quality and horizontally in observable attributes. We are thus concerned with some industry consisting of K submarkets such that the quantity of a good in submarket k is identified by x_k. We assume the industry consists of N_0 total firms, with N 'active' firms in equilibrium, indexed by i, but relax the assumption that all firms are symmetric. Specifically, we assume that there are N_0^L (N^L active) firms with a low cost to R&D and N_0^H (N^H active) high-cost firms.

In developing his endogenous fixed cost (EFC) model, Sutton is primarily concerned with the concept of R&D trajectories and identifying the equilibrium configurations that result from firms' R&D activities. He assumes that the industry consists of M possible research trajectories, indexed by m, such that each is associated with a distinct submarket. Thus, each firm i invests in one or more research programs, each associated with a particular trajectory, and achieves a competence (i.e. quality or capability) defined by an index u_{im} to be associated with some good x_{im}.

Our model diverges from Sutton's (1998) with respect to the concepts of product quality and research trajectories primarily in two dimensions: first, in the definition of quality for some good k; and second, in the relationship between research trajectories and the associated levels of quality. We consider multiple attribute products in which the overall quality u_k of some good k is characterized as a function of the technical competencies achieved across all attributes M^k associated with the good. Specifically, some firm i achieves competence u_k according to:

$$u_k = f\left(v_{i1}, \dots, v_{im}, \dots, v_{iM^k}\right), \tag{1}$$

where v_{im} corresponds to the technical competence that Firm i achieves along research trajectory m. Therefore, we make the minor distinction between the quality of a product directly associated with a distinct research trajectory, as is the case in Sutton's (1998) model, and the quality of a product as a function of the qualities of its individual attributes which are directly associated with distinct research trajectories.[1]

A firm chooses some value $v_{im} \in \{0, [1, \infty)\}$ along each trajectory such that $v_{im} = 0$ corresponds to inactivity along trajectory m and $v_{im} = 1$ corresponds to a minimum level of quality required to offer attribute m. The quality function $f(\cdot)$ is a $M^k \rightarrow 1$ mapping for

[1] This distinction relates, in part, to the discussion on the possibilities of economies of scope across research trajectories as discussed by Sutton (1998) in Appendix 3.2. Implicit in the model proposed here is the assumption that once firms achieve a level of technical competency along some research trajectory, it can utilize this competency across a broad range of products without incurring additional R&D costs.

every product k such that the shape and characteristics of the quality function $f(\cdot)$ satisfy the following assumptions:

(i) Product quality is concave in individual attributes (i.e. $\frac{\partial f}{\partial v_m} \geq 0$, $\frac{\partial^2 f}{\partial {v_m}^2} \leq 0$, and $\frac{\partial^2 f}{\partial v_n \partial v_m} \geq 0$). Thus, firms are limited in their ability to increase the overall quality level of some product k by escalating the competency they acquire along a single trajectory;[2]

(ii) A firm that is inactive along any attribute for some product k achieves a capability equal to the zero (i.e. If $\exists m \in M^k, v_{im} = 0$, then $u_{ik} = 0$.). Thus, firms must achieve at least a minimum level of competency across all trajectories M^k in order to enter the product market for good k; and

(iii) A capability equal to one, associated with a minimum level of quality, indicates that a firm has achieved a minimum level of competency across all trajectories M^k for some product k. (i.e. If $\forall m \in M^k, v_{im} = 1$, then $u_{ik} = 1$.)

Thus, we are left with two possible alternatives with which we can define the overall capability achieved by Firm i: namely, as the K-tuple set of qualities that it achieves in each submarket such that $\mathbf{u}_i = (u_{i1}, \ldots, u_{ik}, \ldots u_{iK})$ or as the M-tuple set of competencies that it achieves in each trajectory such that $\mathbf{v}_i = (v_{i1}, \ldots, v_{im}, \ldots v_{iM})$. Within the product market, we are primarily concerned with the quality levels of the offered products and the resulting configuration of firms given these qualities. Thus, we confine ourselves to considering the

[2] In the case in which a product consists of only a single attribute, then the overall level of quality of the product may be increasing at a constant rate. This case is equivalent to the model proposed by Sutton (1998) in which each product is associated with a distinct research trajectory.

overall capability that Firm i achieves as being represented by $\mathbf{u}_i = \mathbf{u}(\mathbf{v}_i)$ such that $\mathbf{u}_i = \emptyset$ corresponds to the case in which Firm i is inactive in every product.

We follow Sutton (1998) in defining the outcome of the R&D process across all firms in an industry as a configuration such that $\mathbf{u} = (\mathbf{u}_1, \dots, \mathbf{u}_i, \dots, \mathbf{u}_N)$ consists of set of capabilities for all active firms $N = N^H + N^L$. It is useful to also specify several other notations regarding capabilities and configurations, specifically we denote $(\mathbf{u}_{-i})$ as the set of capabilities of Firm i's rivals, define $\hat{u}(\mathbf{u}) = \max_i \max_k u_{ik}$ as the maximum level of quality achieved across all products for some configuration $\mathbf{u}$, and define $\hat{v}_m = \max_i v_{im}$ and $\hat{v} = \max_m \hat{v}_m$ as the maximum level of quality achieved within some attribute m and across all attributes, respectively**.** Moreover, let the set of products offered by Firm i be I, the set of products offered by Firm i that contain attribute m be I_m, and the total set of attributes possessed by Firm i be V^i.

The profit function and sales revenue for Firm i are defined in terms of the set of firm competencies $\mathbf{u}_i$ and the equilibrium configuration $\mathbf{u}$. Total profit for Firm i, written in terms of the number of consumers in the market S and per consumer profit $\pi(\cdot)$, is specified as $S\pi_i(u(\mathbf{v}_i)|\mathbf{u})$. We let profit for Firm i from a single product market k to be specified as $S\pi_{ik}(u(\mathbf{v}_i)|\mathbf{u})$. Additionally for some configuration $\mathbf{u}$, we specify the total sales revenue for Firm i within a single product market k as $Sr_{ik}(\mathbf{u})$, total industry sales summed across all active firms within a single product market k as $Sr_k(\mathbf{u}) = S\sum_{i \in N_k} r_{ik}(\mathbf{u})$, and the total industry sales revenue across all markets, $\mathrm{R}(\mathbf{u}) \equiv Sr(\mathbf{u}) = S\sum_k r_k(\mathbf{u})$.

Suppose that within the set of products K, there is a subset of products H which are characterized by a single attribute h with a corresponding research trajectory. This implies that for this set of products, the quality of the final product is directly comparable to the technical competency achieved along the research trajectory (i.e. $u_{ih} = v_{ih}, \forall h \in H, i \in N_h$). A Firm i that enters the market producing a single product h from this set of products which yields its greatest profit by attaining capability $u_{ih} = \tilde{v}$ earns profit equal to $S\pi\left(\tilde{v}\middle|(\mathbf{u}_{-i})\right)$ and revenue equal to $S\tilde{r}$.

Innovation and market structure are endogenous in Sutton's (1998) bounds model via the presence of sunk cost investments in technology. Specifically, he assumes that there is a minimum setup cost F_0 associated with entry along any trajectory which increases in capability above the minimum involve expenditures in R&D. Thus, the sunk (fixed) R&D outlay by Firm i along trajectory m can be expressed as:

$$F(v_{im}) = F_0 {v_{im}}^{\beta_i}, \quad \beta_i \geq 2 \ \forall i. \tag{2}$$

Here, the restriction on the elasticity of the fixed cost schedule, characterized by the parameter β_i, is required such that the cost of quality increases as rapidly as profits. Moreover, we relax the simplifying assumption that firms face symmetric costs (i.e. $\beta_i = \beta \ \forall i$) and thus we allow for asymmetric costs schedules across firms, implying that there exist potential costs advantages in R&D. The total fixed costs for Firm i across all trajectories V^i in which the firm is active can be expressed as:

$$F(\mathbf{v}_\mathrm{i}) = F_0 \sum_{m \in \mathrm{V}^i} {v_{im}}^{\beta_i}. \tag{3}$$

Additionally, let the R&D spending by Firm i along trajectory m, in excess of the minimum level of investment, be:

$$D(v_{im}) = F(v_{im}) - F_0 = F_0\left({v_{im}}^{\beta_i} - 1\right). \tag{4}$$

such that total R&D spending across all trajectories equals:

$$D(\mathbf{v}_\mathrm{i}) = F_0 \sum_{m \in \mathrm{V}^i} \left({v_{im}}^{\beta_i} - 1 \right) = F(\mathbf{v}_\mathrm{i}) - n_i F_0. \tag{5}$$

where n_i is the total number of trajectories that Firm i enters.

Finally, as Sutton (1998) identifies, it is necessary to make additional assumptions upon the size of the market in order to insure that the level of sales sufficient to sustain some minimal configuration such that at least one firm can be supported in equilibrium. We restrict the domain for the total market size $S \in [1, \infty)$ and assume that the conditions defined by Sutton (1998) in Assumption 3.1 also hold for our model. Generally, this assumption implies: (i) for every nonempty configuration, industry sales revenue approaches infinity as market size approaches infinity; and (ii) there is some nonempty configuration that is viable for market sizes falling within the restricted domain.

B. Licensing in an Endogenous Model of R&D and Market Structure

In addition to the relaxation of the assumption on symmetric firms and the (somewhat trivial) clarification regarding the relationship between product quality, product attributes, and research trajectories, our primary extension of Sutton's (1998) model allows firms to acquire attributes either through their own R&D investments or via the licensing agreements with rivals. Specifically, we permit a single firm to possess a first-mover advantage in the quality choice decision within each research trajectory. Thus, the market leader (or "innovator") decides on the level of R&D investment that it commits in the given trajectory and whether or not it will license the technical competency that it attains. All other firms (or "imitators") face the decision to enter this research trajectory with their own R&D investment and incur the associated fixed cost or, if available, to pursue a license agreement to acquire the level of quality offered by the market leader.

For some research trajectory m, "imitating" licensee Firm i, and "innovating" licensor Firm j, we assume that Firm i and Firm j can credibly commit to a license contract that specifies the upfront, lump sum payment, P_{im}^{j}, from Firm i to Firm j and the level of competence to be transferred v_{jm}. Our assumption of lump sum payments is consistent with the licensing models developed by Katz and Shapiro (1985) and Arora and Fosfuri (2003). As Katz and Shapiro (1985) identify, the presence of information asymmetries over output or imitation of technological innovations implies that the use of a "fixed-fee" licensing contract is optimal.[3] Although the model is characterized by a lump sum, fixed-fee payment for the license, for tractability we assume that Firm j is able to specify this payment as a proportion of the sales revenue earned by Firm i along all products which incorporate the licensed competency along trajectory m. The acquisition of a licensed technology is considered as an alternate to R&D investment while remaining a sunk cost expenditure such that the payment takes the form:

$$P_{im}^{j} = \rho(v_{jm}) S \sum_{k \in I_m} r_{ik}(\acute{\mathbf{u}}), \tag{6}$$

where $\acute{\mathbf{u}}$ is the equilibrium configuration of qualities offered under licensing and $\rho(v_{jm}) \in [0,1]$ is the proportion of sales revenue across all products that incorporate capability v_{jm} that Firm i pays to Firm j.

[3] For a counter-argument regarding the feasibility of lump sum payments in licensing contracts, the reader is referred to Gallini and Winter (1985) who assume per unit royalty fees as lump sum payments and two-part tariffs are "institutionally infeasible" (p. 242, 1985). For a more thorough discussion of the pricing of license agreements, please refer to Gallini and Winter (1990).

We incorporate transactions costs associated with licensing in two ways: first, in the form of a fixed component associated with the formation of each license agreement; and second, in the imperfect transfer of technical competencies between firms. We assume that a firm that licenses technology from a competitor also incurs a fixed transactions cost T_0 associated with each license agreement that is irrecoverable to either contracting firm. This fixed fee can be thought of as the rents captured by some unrelated, third party intermediary negotiating the license agreement between the two firms. The fixed transactions cost and imperfect transfer of technologies introduce inefficiencies into the model under licensing. However, these inefficiencies are counterbalanced by efficiency gains as more firms capitalize upon the same R&D expenditures and as high-cost firms are reduce their inefficient R&D spending such that there is an overall ambiguous effect.

We account for the variable component of the transactions cost via an imperfect transfer of technologies between firms. Specifically, some Firm i that licenses competency v_{jm} from Firm j is only able to utilize a level of competency equal to δv_{jm}, where $\delta \in [0,1]$, without incurring an additional fixed cost of R&D. This implies that for Firm i to achieve the full competency for which it contracted, it must also incur an additional R&D investment equal to $F_0(1-\delta)^{\beta_i} v_{jm}^{\beta_i}$. This imperfect transfer of technology permits us to generalize the case in which firms incur additional investments in order to incorporate the licensed competencies into their own set of offered products.

The total costs associated with Firm i licensing competency v_{jm} from Firm j along trajectory m, and incurring the additional R&D investment to accommodate the licensed technology, can thus be expressed as:

$$T(v_{jm}) = T_0 + P^j_{im} + F\left((1-\delta)v_{jm}\right)$$
$$= T_0 + \rho(v_{jm})S \sum_{k \in I_m} r_{ik}(\acute{\mathbf{u}}) + F_0(1-\delta)^{\beta_i} v_{jm}^{\beta_i}. \quad (7)$$

Assume that a high-cost Firm i produces an industry standard capability $\overline{v}_m$ along R&D trajectories for all $m \neq n$. Now consider the case in which Firm i has a choice between licensing a single capability $\hat{v}_n$ (with total product quality $\hat{u}$) from the market leader and producing capability $\underline{v}_n$ by investing in its own R&D and achieving total product quality $\underline{u}$. The high-cost Firm i will (weakly) prefer a license to incurring the total amount of R&D investment for some quality $\hat{v}_n$ iff:

$$S\pi(\hat{u}|\acute{\mathbf{u}}) - \sum_{m \neq n} F^H(\overline{v}_m) - T(\hat{v}_n) \geq S\pi(\underline{u}|\mathbf{u}) - F^H(\underline{v}_n) - \sum_{m \neq n} F^H(\overline{v}_m). \quad (8)$$

As we are allowing high-cost firms to enter endogenously, in equilibrium the right-hand side of expression (8) will be zero (i.e. additional high-cost firms enter the market until profit net of fixed R&D costs equals zero). Substituting for $T(\hat{v}_n)$ and simplifying, we can derive an expression for the proportion of sales revenue accrued to licensor firms which must be satisfied for high-cost firms to prefer licensing to own R&D. Namely,

$$\rho(\hat{v}_n) \leq \frac{S\pi(\hat{u}|\acute{\mathbf{u}}) - \sum_{m \neq n} F^H(\overline{v}_m) - \left[1 - (1-\delta)^{\beta^H}\right] F^H(\hat{v}_n) - T_0}{S \sum_{k \in \mathrm{I}_m} r_{ik}(\acute{\mathbf{u}})}. \quad (9)$$

A "licensor" firm can extract the total surplus from the license by setting a proportion of sales revenue such that this equation holds with equality. Comparative statics reveal that the proportion of sales revenue that a licensor is able to capture is decreasing monotonically in the fixed transaction cost parameter T_0 (i.e. $\frac{\partial \rho(\hat{v}_n)}{\partial T_0} = \frac{-1}{S \sum_{k \in \mathrm{I}_m} r_{ik}(\acute{\mathbf{u}})} \leq 0$) while it is decreasing and convex in the variable transaction cost parameter δ (i.e.

$\frac{\partial\rho(\hat{v}_n)}{\partial\delta} = \frac{-\beta^H(1-\delta)^{\beta^H-1}F^H(\hat{v}_n)}{S\sum_{k\in\mathrm{I}_m} r_{ik}(\acute{\mathbf{u}})} \leq 0$ and $\frac{\partial^2\rho(\hat{v}_n)}{\partial^2\delta} = \frac{\beta^H(\beta^H-1)(1-\delta)^{\beta^H-2}F^H(\hat{v}_n)}{S\sum_{k\in\mathrm{I}_m} r_{ik}(\acute{\mathbf{u}})} \geq 0$). The upper bound on the proportion of sales revenue that a licensor firm can extract from licensees is decreasing in the transactions costs associated with the licensing agreements such that licensing is not feasible (i.e. $\rho \to 0$) under significant transactions costs.

For tractability, we consider the case of a single attribute products and we assume marginal costs of production are zero equal to such that $S\pi(\hat{u}|\acute{\mathbf{u}}) = S\hat{r}$ and that the proportion of Firm i's sales from products with attribute $\hat{v}_n$ equal γ_n. Under these simplifying assumptions and assuming that licensor firms can appropriate all excess profits, we can examine how the proportion of sales revenue that licensors are able to capture changes with the level of quality licensed. Expression (9) can now be specified as:

$$\rho(\hat{v}_n) = \frac{S\hat{r} - \left[1-(1-\delta)^{\beta^H}\right]F^H(\hat{v}_n) - T_0}{\gamma_n S\hat{r}}. \tag{10}$$

The comparative statics for $\frac{\partial\rho(\hat{v}_n)}{\partial\hat{v}_n}$ are:

$$\frac{\partial\rho(\hat{v}_n)}{\partial\hat{v}_n} = -\frac{\beta^H\left[1-(1-\delta)^{\beta^H}\right]F_0\hat{v}_n{}^{\beta^H-1}}{\gamma_n S\hat{r}} - \frac{\left[1-(1-\delta)^{\beta^H}\right]F_0\hat{v}_n{}^{\beta^H} - T_0}{\gamma_n S\hat{r}^2}\cdot\frac{\partial\hat{r}}{\partial\hat{v}_n}. \tag{11}$$

If fixed transactions costs are minimal (i.e. $T_0 = 0$), the sign of $\frac{\partial\rho(\hat{v}_n)}{\partial\hat{v}_n}$ depends upon the relationship between the average sales revenue (relative to the licensed competency) and the marginal sales revenue. Specifically, the sign of $\frac{\partial\rho(\hat{v}_n)}{\partial\hat{v}_n}$ is given by the relationship $-(\beta^H\frac{\hat{r}}{\hat{v}_n} + \frac{\partial\hat{r}}{\partial\hat{v}_n})$. Given our assumptions over the shape of the revenue function, this relationship implies that the proportion of sales revenue that licensor firms can capture is decreasing in the level of quality licensed. Moreover, the proportion of revenue that can be appropriated by licensor firms is also decreasing in the proportion of total licensee sales revenue from products associated with the licensed competency. This implies that there is a trade-off between "major" innovations in attributes that can be applied across a broad class of products and the proportion of sales revenue that can be captured in the licensing of these innovations.

The comparative static results are consistent with the first proposition of Katz and Shapiro (1985) regarding which innovations will be licensed by firms under a fixed licensing fee and Cournot competition in the product market. Their first proposition essentially implies that firms will engage in licensing over minor (or arbitrarily small) innovations, but that major (or large) innovations will not be licensed. By inspection of equation (9), we can infer that as the market size or the total revenue across all products associated with the licensed competency becomes large, the proportion of the revenues which the licensor can successfully capture approaches zero. Thus, major innovations which either significantly expand the total market size or total sales revenue will be less likely to be licensed as licensees would prefer to pursue their own R&D investments in such innovations.

III. Equilibrium Configurations under Licensing

Now we define the conditions that must be satisfied for some configuration **u** to be an equilibrium without licensing as well as the conditions that must be satisfied for some configuration **ú** to be an equilibrium under licensing. Sutton's viability condition, or "survivorship principle", implies that an active Firm i does not earn negative profits net of avoidable fixed costs in equilibrium. Specifically, we can write this condition using the current notation as:

$$\forall i \in N \quad S\pi_i(u(\mathbf{v}_i)|\mathbf{u}) - F(\mathbf{v}_i) \geq 0. \qquad (V.1)$$

Sutton's (1998) stability condition, or "(no) arbitrage principle", implies that in equilibrium, there are no profitable opportunities remaining to permit entry by a new firm. Specifically, for an entrant firm indexed as Firm $N+1$, the condition can be written as:

$$S\pi_{N+1}(u(\mathbf{v}_{N+1})|\mathbf{u}) - F(\mathbf{v}_{N+1}) \leq 0. \qquad (S.1)$$

Sutton (1998) provides the proof that any outcome that can be supported as a (perfect) Nash equilibrium in pure strategies is also an equilibrium configuration and we forgo any further discussion of the comparability of these results with the results from purely game theoretic models.

These conditions must also hold for a low-cost Firm i producing the highest level of quality $\hat{u}$ and attains the highest level of competency $\hat{v}$ along some trajectory n. The viability condition implies that this firm earns non-negative profits such that:

$$S\pi(\hat{u}|\mathbf{u}) - F^L(\hat{v}) - \sum_{m \neq n} F^L(v_m) \geq 0. \qquad (V.1')$$

The corresponding stability condition, which precludes a low-cost Firm j entering and escalating quality along trajectory n by a factor $\kappa > 1$, is specified as

$$S\pi(\kappa\hat{u}|\mathbf{u}) - F^L(\kappa\hat{v}) - \sum_{m \neq n} F^L(v_m) \leq 0, \quad \forall \kappa > 1. \qquad (S.1')$$

In order to make these conditions comparable, we assume that firms achieve the same level of competency v_m along all trajectories $m \neq n$. As we allow for asymmetry across firms in the R&D cost parameter, in equilibrium only firms facing a low-cost R&D parameter are able to attain the highest levels of competency within any trajectory. Without the assumption that low-cost firms offer the market-leading levels of quality in equilibrium, there would exist profitable opportunities for low-cost firms to enter and escalate quality along trajectories in which high-cost firms offered the highest level of quality.

The assumption of symmetric R&D costs across firms in Sutton (1998) provides for a tractable examination of market structure and R&D intensity, but is unable to explain why some industries are characterized by a subset of market leaders in quality. We relax the assumption of cost symmetry, but restrict the R&D cost function in two ways. First, if some equilibrium configuration satisfies the stability condition for all low R&D cost firms, it will also be satisfied for all high R&D cost firms. Second, a configuration in which a high-cost firm offers the market-leading quality is not stable to entry (and escalation) by a low-cost firm. One final point of interest is that the viability and stability conditions allowing for multiple-attribute products are equivalent to the conditions specified in Sutton (1998) for the subset of products H consisting of a single quality attribute.

Similarly, we can specify the stability and viability conditions for our model which must be satisfied for some configuration **ú** to be an equilibrium under licensing. We differentiate these configurations and competencies from those specified by Sutton (1998) as there is no *a priori* reason to believe that there will be correspondence between the two sets of equilibrium configurations or between the sets of product attributes, although we do anticipate some overlap. For simplicity, we assume that low-cost firms license attributes to high-cost rivals only and do not pursue cross-license agreements with other low-cost firms. If we relax the assumption on cross-license agreements, we would expect to observe increased levels of concentration and ambiguous effects upon R&D as market-leading, low-cost firms are able to successfully sustain a "research cartels" across trajectories. The viability condition for a firm that licenses its technology to rivals can be expressed as:

$$\forall i \in N \quad S\pi_i(u(\acute{\mathbf{v}}_i)|\acute{\mathbf{u}}) - F(\acute{\mathbf{v}}_i) + \sum_{m \in \mathrm{V}^i} \sum_{j \in N_m^i} P_{jm}^i \geq 0. \qquad (V.2)$$

Condition $(V.2)$ implies that every firm that licenses technology in equilibrium earns non-negative profits. The final term in equation $(V.2)$ is the licensing revenue earned by the innovating firm as summed over all R&D trajectories and over all firms that license within each trajectory. Thus, the viability condition implies that the reduction in profits from increased competition (i.e. the rent dissipation effect) is offset by the revenue earned from the licensing agreements (i.e. the revenue effect). The corresponding stability condition for licensor firms is:

$$S\pi_{N+1}(u(\acute{\mathbf{v}}_{N+1})|\acute{\mathbf{u}}) - F(\acute{\mathbf{v}}_{N+1}) + \sum_{m \in \mathrm{V}^{N+1}} \sum_{j \in N_m^{N+1}} P_{jm}^{N+1} \leq 0. \qquad (S.2)$$

The stability condition precludes an additional firm from entering in equilibrium and recouping the fixed costs associated with entry via licensing its quality to rivals.

As was the case which precluded licensing, the viability and stability conditions under licensing must hold for a low-cost licensor Firm i that produces the highest level of quality $\hat{u}'$ and attains the highest level of competency $\hat{v}'$ along some trajectory n. Assuming that the high-quality firm only licenses the competency $\hat{v}'$ that it attains along trajectory n and substituting for the lump-sum licensing payment P, the viability condition $(V.2)$ can be specified as:

$$S\pi(\hat{u}'|\acute{\mathbf{u}}) - F(\hat{v}') - \sum_{m \neq n} F(v_m) + \sum_{j \in N_n^i} \rho(\hat{v}')S \sum_{k \in J_n} r_{jk}(\acute{\mathbf{u}}) \geq 0. \qquad (12)$$

Similarly, the stability condition for licensor firms can be expressed as:

$$S\pi(\kappa\hat{u}'|\acute{\mathbf{u}}) - F(\kappa\hat{v}') - \sum_{m \neq n} F(v_m) + \sum_{j \in N_n^i} \rho(\kappa\hat{v}')S \sum_{k \in J_n} r_{jk}(\acute{\mathbf{u}}) \leq 0, \quad \forall \kappa > 1. \qquad (13)$$

The stability condition under licensing (13) precludes entry by a low-cost innovating firm that escalates product quality by increasing the quality of attribute n by a factor of $\kappa > 1$ and recoups the additional fixed cost investments via licensing to high-cost rivals. Moreover, we also specify a stability condition for licensor firms which precludes entry by a low-cost innovating firm that escalates product quality and chooses not to license to high-cost rivals. Specifically,

$$S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}') - F(\kappa\hat{v}') - \sum_{m \neq n} F(v_m) \leq 0, \quad \forall\kappa > 1. \tag{14}$$

Equation (14) implies that, in equilibrium, an innovating firm cannot profitably enter via quality escalation and not licensing its higher quality when it observes licensing within the industry. The rent dissipation effect associated with the licensing of technology or quality to competitors implies that a firm escalating quality and entering without licensing to competitors earns greater profit relative to a firm that escalates and enters with licensing. Thus, $S\pi(\kappa\hat{u}'|\mathbf{\acute{u}})$ is necessarily no greater than $S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}')$ such that equation (13) does not cover all potential profitable opportunities for entry and equation (14) is also necessary.

Let the number of licenses of attribute n granted by Firm i be equal to L^{in} and assume that a potential entrant firm that attempts to escalate quality chooses to grant the same number of licenses L^n. The assumption fixing the number of licensee firms can be thought of as follows: consider some Firm i as the market leader along some R&D trajectory m in which its technology is considered as an industry standard. Thus, there exist conditions in which it is profitable for Firm i's rivals to license the technology rather than pursue their own R&D expenditure such that Firm i can choose the number of rivals that it competes against. By symmetry of profit functions across firms, we assume that an entrant firm that attempts to establish a new technology standard along trajectory m by escalating the capability by some positive factor κ will chose the same number of rivals as that chosen by Firm i.

Finally, we make two non-trivial simplifying assumptions in order to provide clearer intuition over the viability and stability conditions under licensing. First, we assume that the sales from all of the products that incorporate a licensed attribute n can be expressed as a proportion $\gamma_n \in [0,1]$ of total firm sales. Second, we assume zero marginal costs of production such that firm profit functions and firm sales functions for some configuration $\acute{\mathbf{u}}$ are equivalent. Although zero marginal costs is a potentially strong assumption, many of the industries with which we are concerned, including pharmaceuticals, biotechnology, and semiconductors, are characterized by production processes with negligible or zero marginal costs to production. Under these two assumptions, we can specify the proportion of sales revenue specified by the lump-sum transfer for the licensing of some attribute n with quality $\hat{v}'$ to Firm j as:

$$\rho(\hat{v}')S\sum_{k\in J_n} r_{jk}(\acute{\mathbf{u}}) = \rho(\hat{v}')S\gamma_n r_j(\acute{\mathbf{u}}) = \rho(\hat{v}')\gamma_n S\pi(\hat{u}'|\acute{\mathbf{u}}). \tag{15}$$

Under these additional assumptions, the viability and stability conditions for all firms that license some attribute n with quality $\hat{v}'$ can now be characterized as:

$$[1 + L^n\rho(\hat{v}')\gamma_n]S\pi(\hat{u}'|\acute{\mathbf{u}}) - F^L(\hat{v}') - \sum_{m\neq n} F^L(v_m) \geq 0, \tag{$V.2'$}$$

$$[1 + L^n\rho(\kappa\hat{v}')\gamma_n]S\pi(\kappa\hat{u}'|\acute{\mathbf{u}}) - F^L(\kappa\hat{v}') - \sum_{m\neq n} F^L(v_m) \leq 0, \quad \forall\kappa > 1, \tag{$S.2'$}$$

$$S\pi(\kappa\hat{u}'|\acute{\mathbf{u}}') - F^L(\kappa\hat{v}') - \sum_{m\neq n} F^L(v_m) \leq 0, \quad \forall\kappa > 1. \tag{$S.2''$}$$

In order to specify the stability and viability conditions that must be satisfied by firms that license technology in equilibrium, let the set of trajectories along which Firm i licenses technology be V_l^i and the set of trajectories along which it invests in its own R&D be V_{-l}^i. The licensee viability condition ensures that high-cost firms that license technology from their low-cost rivals earn profits that cover the fixed R&D costs along all trajectories in which they do not license technology, the fixed R&D costs associated with the "catch-up" from the imperfect transfer of technology, the lump-sum license fee, and the fixed transactions costs associated with licensing. Thus, for all licensee firms i:

$$\forall i \in N \quad S\pi_i(u(\acute{\mathbf{v}}_i)|\acute{\mathbf{u}}) - \sum_{m \in \mathrm{V}_{-l}^i} F^H(v_{im}) - \sum_{m \in \mathrm{V}_l^i} \sum_{j \in N_{im}^j} T\big(v_{jm}\big) \geq 0. \qquad (V.3)$$

Similarly, the stability condition for licensee firms implies that a firm cannot enter via licensing and escalate quality and recoup the costs associated with licensing and R&D. Namely,

$$S\pi_{N+1}(u(\acute{\mathbf{v}}_{N+1})|\acute{\mathbf{u}}) - \sum_{m \in \mathrm{V}_{-l}^{N+1}} F^H(v_{N+1m}) - \sum_{m \in \mathrm{V}_l^i} \sum_{j \in N_{im}^{N+1}} T(v_{N+1m}) \leq 0. \qquad (S.3)$$

Again, consider the case in which high-cost firms license competency $\hat{v}'$ along a single trajectory n, produces quality $\hat{u}'$, and attains the same levels of competency along every other trajectory $m \neq n$. The viability condition can be expressed as:

$$S\pi(\hat{u}'|\acute{\mathbf{u}}) - \sum_{m \neq n} F^H(v_{im}) - \big[1 - (1-\delta)^{\beta^H}\big] F_0 \hat{v}'^{\beta^H} - \rho(\hat{v}') S \sum_{k \in I_n} r_{ik}(\acute{\mathbf{u}}) - T_0 \geq 0. \qquad (16)$$

In equilibrium, the stability condition for the licensee must hold such that a firm that licenses technology from the market leader cannot then escalate the level of quality provided by escalating its own R&D expenditure. Thus, equilibrium configurations preclude cases in which licensee firms can acquire technology "cheaply" from rivals and then pursue their own R&D to escalate the overall level of quality. The explicit expression of the stability condition in this case is:

$$S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}') - \sum_{m\neq n} F^H\big(v_{jm}\big) - \kappa^{\beta^H}\big[1-(1-\delta)^{\beta^H}\big]F_0\hat{v}'^{\beta^H} \\ -\rho(\hat{v}')S\sum_{k\in J_n} r_{jk}(\mathbf{\acute{u}}) - T_0 \leq 0, \quad \forall\kappa > 1. \tag{17}$$

We also specify a second stability condition such that a high-cost entrant that licenses the current maximum quality, escalates this quality through its own R&D, and then licenses to other high-cost firms is not a feasible equilibrium strategy. Explicitly, this stability condition can expressed as:

$$S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}') - \sum_{m\neq n} F^H\big(v_{jm}\big) - \kappa^{\beta^H}\big[1-(1-\delta)^{\beta^H}\big]F_0\hat{v}'^{\beta^H} - \rho(\hat{v}')S\sum_{k\in J_n} r_{jk}(\mathbf{\acute{u}}) \\ -T_0 + \sum_{j\in N_n^i} \rho(\kappa\hat{v}')S\sum_{k\in J_n} r_{jk}(\mathbf{\acute{u}}) \leq 0, \quad \forall\kappa > 1. \tag{18}$$

Again, under the same assumptions of zero marginal costs and the specification of sales revenue from associated products as a percentage of total sales revenue, the viability and stability conditions can be specified as:

$$[1-\rho(\hat{v}')\gamma_n]S\pi(\hat{u}'|\mathbf{\acute{u}}) - \sum_{m\neq n} F^H(v_m) - \big[1-(1-\delta)^{\beta^H}\big]F_0\hat{v}'^{\beta^H} - T_0 \geq 0, \tag{$V.3'$}$$

$$S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}) - \rho(\hat{v}')\gamma_n S\pi(\hat{u}'|\mathbf{\acute{u}}) - \sum_{m\neq n} F^H(v_m) \\ -\kappa^{\beta^H}\big[1-(1-\delta)^{\beta^H}\big]F_0\hat{v}'^{\beta^H} - T_0 \leq 0, \quad \forall\kappa > 1. \tag{$S.3'$}$$

$$[1+L^n\rho(\kappa\hat{v}')\gamma_n]S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}) - \rho(\hat{v}')\gamma_n S\pi(\hat{u}'|\mathbf{\acute{u}}) - \sum_{m\neq n} F^H(v_m) \\ -\kappa^{\beta^H}\big[1-(1-\delta)^{\beta^H}\big]F_0\hat{v}'^{\beta^H} - T_0 \leq 0, \quad \forall\kappa > 1. \tag{$S.3''$}$$

For a configuration to be an equilibrium configuration under licensing, the viability conditions for both licensors ($V.2'$) and licensees ($V.3'$) as well as the entire set of stability conditions $(S.2', S.2'', S.3', S.3'')$ must hold. If the first (second) viability condition is violated, then licensing is not profitable or sustainable for the innovating (imitating) firm. Moreover, if any of the three stability conditions does not hold, the equilibrium configuration is not stable to entry by a quality-escalating firm, with or without licensing.

Without further restrictions upon the model or specific parameter values, we cannot determine whether the licensor or the licensee conditions provide the binding constraint on the feasible set of equilibrium configurations. However, we can make some inferences regarding the scenarios and parameter values at which each of the conditions is likely to be binding. In order to derive a benchmark, consider the case in which firms do not license their technology to rivals such that the relevant viability and stability conditions are $(V.1)$ and $(S.1)$. Combining these two conditions, we observe that the feasible set of equilibrium configurations is defined by the profit function and escalation parameter $\kappa > 1$ such that:

$$S\pi(\hat{u}|\mathbf{u}) \geq \frac{1}{\kappa^{\beta^L}} S\pi(\kappa\hat{u}|\mathbf{u}) + \left(\frac{\kappa^{\beta^L}-1}{\kappa^{\beta^L}}\right) \sum_{m\neq n} F^L(v_m). \tag{19}$$

This condition implies that allowing for quality differences in multiple attribute products decreases the set of feasible equilibrium configurations relative the case of single attribute products. Similarly, combining the viability $(V.2')$ and stability $(S.2', S.2'')$ conditions that must hold for licensor firms yields the expressions:

$$S\pi(\hat{u}'|\acute{\mathbf{u}}) \geq \frac{1}{\kappa^{\beta^L}} \left[\frac{1 + L^n\rho(\kappa\hat{v}')\gamma_n}{1 + L^n\rho(\hat{v}')\gamma_n}\right] S\pi(\kappa\hat{u}'|\acute{\mathbf{u}}) + \left(\frac{\kappa^{\beta^L}-1}{\kappa^{\beta^L}}\right)\left[\frac{\sum_{m\neq n} F^L(v_m)}{1 + L^n\rho(\hat{v}')\gamma_n}\right]. \tag{20}$$

$$S\pi(\hat{u}'|\acute{\mathbf{u}}) \geq \frac{1}{\kappa^{\beta^L}} \left[\frac{1}{1 + L^n\rho(\hat{v}')\gamma_n}\right] S\pi(\kappa\hat{u}'|\acute{\mathbf{u}}') + \left(\frac{\kappa^{\beta^L}-1}{\kappa^{\beta^L}}\right)\left[\frac{\sum_{m\neq n} F^L(v_m)}{1 + L^n\rho(\hat{v}')\gamma_n}\right]. \tag{21}$$

By inspection, we observe that the stability condition $(S.3')$ is a special case of the second stability condition $(S.3'')$ in which the licensee entrant does not choose to license its escalated quality. Thus, we can derive a similar condition for the feasible set of equilibrium configurations as determined by the viability $(V.3')$ and stability $(S.3'')$ conditions for licensee firms. Namely,

$$S\pi(\hat{u}'|\mathbf{u}) \geq \frac{1}{\kappa^{\beta^H}}\left[\frac{1+L^n\rho(\kappa\hat{v}')\gamma_n}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\rho(\hat{v}')\gamma_n}\right]S\pi(\kappa\hat{u}'|\acute{\mathbf{u}}) + \left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\left[\frac{\sum_{m\neq n}F^H(v_m)+T_0}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\rho(\hat{v}')\gamma_n}\right]. \quad (22)$$

Prior to examining the condition on the feasible set of equilibrium configurations, it is important to recall that the viability and stability conditions for licensee firms are defined only over firms with high costs to R&D. For some quality escalation parameter $\kappa > 1$, the additional fixed cost incurred by firms with high R&D costs is greater than that incurred by firms with low R&D costs (i.e. $\forall\kappa > 1, \kappa^{\beta^H} > \kappa^{\beta^L}$) since $\beta^H > \beta^L$ by assumption. The R&D cost asymmetry and fixed transactions costs with licensing imply that the second term on the right-hand side of equation (22) is greater than the second term on the right-hand side of equations (19)-(21) and thus a more restrictive set of feasible equilibrium configurations when transactions costs are large relative to firm profit.

<u>Proposition 1</u>: For some quality escalation parameter $\kappa > 1$ under weak product market competition, the feasible set of equilibrium configurations under licensing is determined by the licensor viability $(V.2')$ and stability $(S.2')$ conditions if: $\rho(\kappa\hat{v}') \geq \frac{1}{L^n\gamma_n}\left[\frac{S\pi(\kappa\hat{u}'|\acute{\mathbf{u}}')}{S\pi(\kappa\hat{u}'|\mathbf{u})} - 1\right]$ and $\rho(\hat{v}') \leq \frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H}-\kappa^{\beta^L}}{\kappa^{\beta^L}L^n+\kappa^{\beta^H}-1}\right], \quad \forall\kappa > 1.$

Corollary to Proposition 1: For some quality escalation parameter $\kappa > 1$ under intense product market competition, the feasible set of equilibrium configurations under licensing is determined by the licensor viability $(V.2')$ and stability $(S.2'')$ conditions if: $\rho(\kappa\hat{v}') \leq \frac{1}{L^n \gamma_n}\left[\frac{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}')}{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}})} - 1\right]$ and $\rho(\hat{v}') \leq \frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H} - \kappa^{\beta^L}}{\kappa^{\beta^L} L^n + \kappa^{\beta^H} - 1}\right]$, $\quad \forall\kappa > 1$.

Proof of Proposition 1 and Corollary: See Appendix A.

Proposition 1 and its Corollary imply that the relevant licensor stability condition for the binding set of feasible equilibria will be determined by the rent dissipation effect from licensing of technology which relates to the competitiveness of the product market. Rent dissipation from licensing refers to our assumption that the escalating firm's profit under licensing is no greater than the escalating firm's profit without licensing. Thus, the term in the braces on the right-hand side of the first equation is, by assumption, greater than or equal to 0. As the rent dissipation effect becomes smaller, the stability condition on a licensing, quality-escalating entrant are more likely to provide the binding constraint on equilibrium configurations (i.e. if $\rho(\kappa\hat{v}) \geq \frac{1}{L^n \gamma_n}\left[\frac{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}')}{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}})} - 1\right]$, then condition (20) characterizes the feasible equilibrium configurations).

By inspection of Proposition 1 and its Corollary, we can determine that the licensee viability $(V.3')$ and stability $(S.3'')$ conditions will define the feasible set of equilibrium configurations independently of the binding licensor conditions iff: $\rho(\hat{v}) \geq \frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H} - \kappa^{\beta^L}}{\kappa^{\beta^L} L^n + \kappa^{\beta^H} - 1}\right]$, $\quad \forall\kappa > 1$. Thus, we can interpret when the licensee viability and stability conditions are likely to provide the binding set of feasible equilibrium strategies.

First, for minor innovations or small escalations of quality (i.e. $\kappa \to 1$), the right-hand side of condition on $\rho(\hat{v})$ approaches zero such that all fixed-fee royalty payments offered by licensors will be feasible. As $\rho(\hat{v}), \gamma_n \in [0,1]$, we can determine that as the proportion of total sales revenue from products associated with the licensed attribute becomes small (i.e. $\gamma_n \to 0$), the viability and stability conditions on licensee firms are less likely to be binding as quality-leading firms would require a fixed-fee royalty payment $\rho(\hat{v})$ that was excessively large.

Thus, attributes that are incorporated into products that contribute to a small proportion of total licensee sales revenues will be unlikely candidates for licensing as licensor firms would require high rates of royalty payments. However, as the proportion of total sales revenue increases, licensor firms require a smaller proportion of firm profits be appropriated under the licensing agreements. Finally, as the R&D cost differential between low- and high-cost firms becomes larger, licensor firms can appropriate a greater proportion of firm sales revenue from the licensed technology. Thus, as the cost differential between types of firms decreases such that innovators lose their R&D cost advantage, licensor firms require a smaller proportion of sales in equilibrium.

Finally, our analysis of the feasible set of equilibrium configurations was limited to the cases in which we observe licensing. As the configuration of capabilities with and without licensing, as well as the maximum quality offered, are not necessarily equivalent, a direct comparison between the feasible set of equilibrium configurations according to Sutton's (1998) model under asymmetric costs and multiple products is uninformative. However, it is important to note that the "No Licensing" case is implicitly embedded in each of the "Licensing" conditions by either setting the total number of licenses L^n or the fixed-fee royalty payment $\rho(\hat{v}')$ equal to zero.

IV. Bounds to Concentration under Licensing

The primary result of Sutton's (1998) endogenous fixed cost model ("bounds" model), is that there exists a lower bound to the market share of the high quality firm and R&D/sales ratio of the high quality firm that is independent of the configuration of capabilities and the size of the market. Thus, as market size increases, the market share of the high quality firm in the endogenous sunk cost industry does not converge to zero, the result implied by industries characterized by exogenous sunk costs. Moreover, Sutton finds that as market size increases, the R&D/sales ratio of the firm offering the maximum quality is bounded from below by the same parameter alpha. Subsequently, Sutton proceeds in identifying the relevant industry characteristics by which it is possible to classify an industry as being described by a bounded, endogenous fixed cost model.

We define a lower bound theorem under licensing to motive the analysis of bounds to concentration and escalation of sunk costs in R&D under licensing. Thus far, we have extended Sutton's (1998) model along three dimensions by incorporating multiple attribute products, relaxing the assumption on symmetry of R&D costs across firms, and allowing firms to acquire a product characteristic via licensing rather than R&D. Given these extensions, we formulate four alternative propositions for the potential lower bound to concentration as we are unable to distinguish *a priori* which of the lower bounds to concentration will be binding.

We define the minimum ratio $a(\kappa)$ of firm profit to industry sales for every value of κ, independently of market size and capability configuration, such that:

$$a(\kappa) \equiv \inf_{\mathbf{u}} \frac{\pi(\kappa \hat{u} | \mathbf{u})}{r(\mathbf{u})}. \tag{23}$$

Moreover, we also define a corresponding minimum ratio $\acute{a}(\kappa)$ for equilibrium configurations under licensing for every value of κ such that:

$$\acute{a}(\kappa) \equiv \inf_{\acute{\mathbf{u}}} \frac{\pi(\kappa \hat{u}' | \acute{\mathbf{u}})}{r(\acute{\mathbf{u}})}. \tag{24}$$

Thus, for a given configuration under licensing **ú** and maximum quality $\hat{u}$, an entrant firm chooses to enter with capability $\kappa\hat{u}$ along the trajectory which yields greatest profit $S\pi(\kappa\hat{u}'|\acute{\mathbf{u}})$. From the definitions of $a(\kappa)$ and $\acute{a}(\kappa)$, this profit is at least $a(\kappa)Sr(\mathbf{u})$ and $\acute{a}(\kappa)Sr(\acute{\mathbf{u}})$, respectively, independently from a given configuration (**ú**,**u**) and market size S.

<u>Proposition 2</u>: (Lower Bound under Multiple Attribute Products) Given any pair $(\kappa, a(\kappa))$, for any configuration **u** to be an equilibrium configuration a low-cost firm offering the highest level of quality has a share of industry revenue exceeding $\frac{a(\kappa)}{\kappa^{\beta^L}}$ as the size of the market becomes large. Under finitely-sized markets and multiple attributes, the lower bound to the share of industry revenue is greater than $\frac{a(\kappa)}{\kappa^{\beta^L}}$.

Proof of Proposition 2: See Appendix B.

Proposition 2 implies that as the market size becomes large, the presence of multiple attribute products and asymmetric R&D costs alone does not change the lower bound to the market share of the quality-leading firm relative to that found in Sutton (1998). For finitely-sized markets however, multiple attributes products raise the lower bound to concentration such that the share of the market leader is convergent in market size.

Proposition 3: (Lower Bound under Licensing-1) Given any pair $\left(\kappa, \acute{a}(\kappa)\right)$, an equilibrium configuration **ú** under licensing in which a low-cost firm which offers the highest level of quality and licenses its competency to rivals has a share of industry revenue exceeding $\frac{\acute{a}(\kappa)}{\kappa\beta^L} \cdot \left[\frac{1+L^n\gamma_n\rho(\kappa\hat{v}\prime)}{1+L^n\gamma_n\rho(\hat{v}\prime)}\right]$ as the size of the market becomes large.

Corollary to Proposition 3: (Lower Bound under Licensing-2) Given any pair $\left(\kappa, \acute{a}(\kappa)\right)$, an equilibrium configuration **ú** under licensing in which a low-cost firm which offers the highest level of quality and licenses its competency to rivals has a share of industry revenue exceeding $\frac{\acute{a}(\kappa)}{\kappa\beta^L} \cdot \left[\frac{\varphi}{1+L^n\gamma_n\rho(\hat{v}\prime)}\right]$ as the size of the market becomes large where φ is some constant greater or equal to one.

Proof of Proposition 3 and Corollary to Proposition 3: See Appendix B.

From our comparative statics over the proportion of sales revenue that licensor firms can appropriate from licensee firms, we know that $\frac{\partial\rho(\hat{v}\prime)}{\partial\hat{v}\prime} \leq 0$ such that a low-cost entrant that escalates competency $\hat{v}$ along trajectory n earns a smaller proportion of licensee sales revenue. Applying this comparative static to Proposition 3 for a fixed number of licenses L^n implies that $\left[\frac{1+L^n\gamma_n\rho(\kappa\hat{v}\prime)}{1+L^n\gamma_n\rho(\hat{v}\prime)}\right] \leq 1$ and that the lower bound to the market share of the quality-leader is lower under licensing compared to the case without licensing if $(S.2')$ is the binding stability condition on licensors. Moreover, when $(S.2')$ is the relevant stability condition such that Proposition 3 holds, the lower bound to market share is increasing at a decreasing rate in the number of licenses if $\rho(\kappa\hat{v}') > \rho(\hat{v}')$ (i.e. $\frac{\partial}{\partial L^n} \geq 0$ and $\frac{\partial^2}{\partial L^{n^2}} \leq 0$). Additional comparative statics on the proportion of total firm revenue associated with the licensed technology also imply that the lower bound to market share of the quality leader is increasing at a decreasing rate in γ_n(i.e. $\frac{\partial}{\partial \gamma_n} \geq 0$ and $\frac{\partial^2}{\partial \gamma_n^{2}} \leq 0$).

The Corollary to Proposition 3 implies a lower bound to market share that is greater under licensing if $\left[\frac{\varphi}{1+L^n\gamma_n\rho(\hat{v}')}\right] \geq 1$. Equivalently, this can be expressed in terms of the proportion of sales accrued to the licensor such that the lower bound under licensing is greater if $\rho(\hat{v}') \leq \frac{1}{L^n\gamma_n}[\varphi - 1]$. In Proposition 1, we determined an equivalent expression in order for $(S.2'')$ to be the relevant stability condition such that $\rho(\kappa\hat{v}') \geq \frac{1}{L^n\gamma_n}[\varphi - 1]$. A necessary, but not sufficient, condition for the lower bound to be greater under licensing when $(S.2'')$ is the relevant stability condition is that $\rho(\kappa\hat{v}') \geq \rho(\hat{v}')$. Comparative statics on the Corollary to Proposition 3 imply that the lower bound to market share in this case is decreasing at an increasing rate in the number of licenses and in the proportion of firm sales associated with the licensed technology (i.e. $\frac{\partial}{\partial L^n}, \frac{\partial}{\partial \gamma_n} \leq 0$ and $\frac{\partial^2}{\partial L^{n^2}}, \frac{\partial^2}{\partial \gamma_n^{2}} \geq 0$). As φ captures the extent that licensing dissipates rents, it is interesting to note that the lower bound to concentration is monotonically increasing in this parameter implying a greater lower bound as the substitution effect of licensing upon licensors is larger (i.e. $\frac{\partial}{\partial \varphi} \geq 0$).

Proposition 4: (Lower Bound under Licensing-3) Given any pair $(\kappa, \acute{a}(\kappa))$, for any configuration **ú** to be an equilibrium configuration with licensing a firm with the highest level of quality that licenses its competency to rivals has a share of industry revenue exceeding $\frac{\acute{a}(\kappa)}{\kappa^{\beta^H}} \cdot \left[\frac{1+L^n \gamma_n \rho(\kappa \hat{v}\prime)}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\gamma_n \rho(\hat{v}\prime)}\right]$ as the size of the market becomes large.

Proof of Proposition 4: See Appendix B.

Unlike the cases in which the licensor stability conditions were the binding constraints upon equilibrium configurations, the lower bound to market concentration derived from the licensee conditions is not straightforward to interpret. Specifically, as we allow for asymmetric R&D costs, the first term in the lower bound condition in Proposition 4 is strictly less than the first term derived in the previous propositions as $\beta^H > \beta^L$. However, considering the special case in which the proportion of sales revenue accrued to the licensor is constant (i.e. $\rho(\kappa\hat{v}') = \rho(\hat{v}') = \rho$), we find that the lower bound under the licensee conditions is greater if $\rho \geq \frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H} - \kappa^{\beta^L}}{\kappa^{\beta^L} L^n + \kappa^{\beta^H} - 1}\right], \kappa \geq 1$. Comparative statics reveal that this bound is increasing at a constant rate in the number of licenses (i.e. $\frac{\partial}{\partial L^n} \geq 0$) and increasing at an increasing rate in the proportion of total sales revenue associated with the licensed technology trajectory (i.e. $\frac{\partial}{\partial \gamma_n} \geq 0$ and $\frac{\partial^2}{\partial {\gamma_n}^2} \geq 0$). Given the lower bound to the share of industry revenue accrued to the market leader in quality varies if it is derived from the licensor and licensee stability conditions, we further analyze the potential embedding of Proposition 3 and its Corollary into Proposition 4 and derive a general theorem of non-convergence under licensing.

Theorem 1: (Lower Bound under Licensing) Given any pair $(\kappa, \acute{a}(\kappa))$ and some feasible[4] royalty payment $\rho(\hat{v}') \geq \frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H}-\kappa^{\beta^L}}{\kappa^{\beta^L}L^n+\kappa^{\beta^H}-1}\right], \forall\kappa \geq 1$, the feasible set of equilibrium configurations **ú** are characterized by the viability $(V.3')$ and stability $(S.3'')$ conditions of licensee firms such that the firm producing (and licensing) the greatest competency $\hat{v}'$ (and corresponding the highest quality $\hat{u}'$) has a share of industry revenue exceeding:

$$\frac{\acute{a}(\kappa)}{\kappa^{\beta^H}} \cdot \left[\frac{1+L^n\gamma_n\rho(\kappa\hat{v}')}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\gamma_n\rho(\hat{v}')}\right] + \left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\left[\frac{\sum_{m\neq n} F^H(\overline{v}_m)+T_0}{\left[1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\gamma_n\rho(\hat{v}')\right]Sr(\mathbf{ú})}\right]. \qquad (25)$$

This condition converges to $\frac{\acute{a}(\kappa)}{\kappa^{\beta^H}} \cdot \left[\frac{1+L^n\gamma_n\rho(\kappa\hat{v}')}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\gamma_n\rho(\hat{v}')}\right]$ as market size increases (i.e. $S \to \infty$) such that all equilibrium configurations with a finitely "small" market size are bounded away from the convergent threshold by some factor of the fixed transactions costs associated with licensing and R&D investment along all other trajectories.

Corollary to Theorem 1: The lower bound to market concentration under licensing embeds the lower bound to concentration derived by Sutton (1998) as a special case in which firms do not license their technology to rivals (and if markets are sufficiently large or products are characterized by a single attribute). Under sufficiently large markets, the

[4] Here, "feasible" implies that the licensee viability condition $(V.3')$ is satisfied such that: $\rho(\hat{v}') \leq \frac{1}{\gamma_n}\left[1-\frac{\sum_{m\neq n} F^H(v_m)+\left[1-(1-\delta)^{\beta^H}\right]F^H(\hat{v}')+T_0}{S\acute{r}}\right]$.

lower bound under licensing is strictly larger relative to the lower bound derived by Sutton (1998). Moreover, when products consist of multiple attributes and there is technology licensing in equilibrium, the lower bound to market concentration under licensing is greater than the lower bound derived by Sutton. Finally, for finitely-sized markets, the lower bound is not independent of the size of the market and is greater if there exist transactions costs associated with licensing.

Proof of Theorem 1 and Corollary to Theorem 1: See Appendix C.

In Theorem 1, we derive the lower bound to concentration under licensing given our set of Propositions over the feasible set of equilibrium configurations and their respective lower bounds. In the limit as $\rho(\hat{v}')$ and $\rho(\kappa\hat{v}')$ both approach the lower bound (i.e. $\rho(\hat{v}'), \rho(\kappa\hat{v}') \to \frac{1}{\gamma n}\left[\frac{\kappa^{\beta^H} - \kappa^{\beta^L}}{\kappa^{\beta^L} L^n + \kappa^{\beta^H} - 1}\right]$), then the lower bound under licensing approaches the lower bound that we found without licensing (if transactions costs are minimal or market size is large). Additionally, it is interesting to note that lower bound to market share of the quality leader under licensing embeds the lower bound found by Sutton (1998) in the case in which the proportion of revenue accrued to the licensor and the total number of licenses equal zero.

As there are a number of differences between the lower bound derived under licensing with multiple attribute products and the lower bound derived by Sutton (1998), it is beneficial to consider some general comparative statics in order to understand how the level of the bound changes with the model parameters. The royalty percentage that a low-cost quality leader can charge to a high-cost firm for some competency $\hat{v}'$ is decreasing at an increasing rate in the number of licenses granted (i.e. $\frac{\partial\rho(\hat{v}')}{\partial L^n} \leq 0$, $\frac{\partial^2\rho(\hat{v}')}{\partial^2 L^n} \geq 0$) whereas the lower bound to concentration is increasing at a constant rate (i.e. $\frac{\partial\cdot}{\partial L^n} \geq 0$). The first comparative static implies that there is a trade-off in the market share of sales for firms offering the highest quality with the number of licenses that it grants. The comparative static on the lower bound to concentration illustrates licensor firms requiring greater levels of market concentration in exchange for each additional license.

The lower bound to the ratio of the sales of the high-quality firm to the industry sales motivates Sutton's (1998) definition of the escalation parameter alpha. For any value of $\kappa > 1$, alpha is defined as:

$$\alpha \equiv \sup_{\kappa} \frac{a(\kappa)}{\kappa^{\beta^L}}. \tag{26}$$

Subsequently, the one-firm sales concentration ratio C_1 cannot be less than the share of industry sales revenue of the high-quality firm. Thus, for any equilibrium configuration with high quality $\hat{u}$ and competency $\hat{v}$, C_1 is bounded from below by α. In our examination of multiple attribute products without licensing (Prop. 2) we found a lower bound to concentration that was equivalent to Sutton's lower bound for large markets. Moreover, by fixing the royalty payment and number of licenses to be zero in Prop. 3, in the Corollary to Prop. 3, and in Prop. 4, Sutton's lower bound to concentration is also embedded as a special case of the general model.

However, given that we have determined that the binding conditions on equilibrium configurations of capabilities under licensing is derived from the viability and stability conditions of high-cost licensee firms (Theorem 1), we must consider an alternate definition of alpha which incorporates the fixed royalty payment $\rho(\hat{v}')$, the total number of licenses L^n, the proportion of sales of products associated with the licensed competency γ_n, and the level of escalation κ. For a high-cost firm, we define the escalation parameter alpha as derived from equation (25) under sufficiently large market sizes such that:

$$\acute{\alpha} \equiv \sup_{\kappa} \frac{\acute{a}(\kappa)}{\kappa^{\beta^H}} \cdot \left[\frac{1 + L^n \gamma_n \rho(\kappa \hat{v}')}{1 - \left(\frac{\kappa^{\beta^H} - 1}{\kappa^{\beta^H}}\right) \gamma_n \rho(\hat{v}')} \right]. \tag{27}$$

It is important to note that the definition of $\acute{\alpha}$ is determined by a licensee that potentially escalates competency (quality) to a level greater than that which has been licensed. The total number of licenses and the royalty payments are taken as exogenous to these potential entrants firms. This definition of $\acute{\alpha}$ allows us to determine a bound to concentration that holds in the limit under no licensing (i.e. $L^n = 0$ and $\rho(\hat{v}') = 0$) which is equivalent to the condition derived by Sutton (1998). We now derive a lower bound to the R&D/sales ratio for the quality leader for the case in which the quality leader produces maximum competency $\hat{v}'$ along some trajectory n and produces the minimum competency along all other trajectories.

<u>Theorem 2</u>: (Lower Bound to R&D-Intensity) For any equilibrium configuration, the R&D/sales ratio for the low-cost market leader firm, offering maximum quality $\hat{u}'$ by achieving competency $\hat{v}'$ along a single trajectory and producing industry standard quality along all other trajectories, is bounded from below as the size of the market becomes large by: $\acute{\alpha}\kappa^{\beta^H - \beta^L} \left[1 - \left(\frac{\kappa^{\beta^H} - 1}{\kappa^{\beta^H}}\right) \gamma_n \rho(\hat{v}')\right], \forall \kappa > 1$.

Proof of Theorem 2: See Appendix C.

Sutton's (1998) EFC model predicted an identical lower bound to market concentration and R&D intensity as the size of the market became large. In contrast, we find that the when firms are able to license their technology to competitors, both the lower bound to market concentration and R&D intensity are greater relative to the case without licensing, but are no longer identical. Specifically, permitting low-cost firms to license their technology to high-cost rivals encourages more intensive R&D as "innovator" firms realize efficiency gains from licensing. Thus, greater market concentration and more intensive and efficient R&D would have ambiguous effects upon consumer welfare.

V. Conclusion

Within a multiple product, multiple attribute framework, we extended the endogenous fixed cost (EFC) model developed by Sutton (1998; 2007) and incorporated a specific strategic alliance, namely licensing and cross-licensing, into the endogenous determination of market structure and innovation. We develop an EFC model under licensing that endogenizes the technology licensing decision by firms and relaxes the assumption of symmetric R&D costs. For finitely-sized markets, the presence of multiple research trajectories and fixed transactions costs associated with licensing raised the lower bound to market concentration under licensing relative to the bound in which firms invest along a single R&D trajectory or in which transactions costs associated with licensing are negligible. Moreover, we found that the lower bound to R&D intensity is strictly greater than the lower bound to market concentration under licensing whereas Sutton (1998) found equivalent lower bounds. This implies that we would expect a greater level of R&D

intensity within industries in which licensing is prevalent as innovating firms are able to recoup more of the sunk costs associated increased R&D expenditure and higher quality.

The results of the theoretical model are consistent with previous models of strategic licensing between competitors in which the availability of licensing creates incentives for firms to choose their competition as well as economize on R&D expenditures. Namely, we find that given sufficiently strong patent protection, it can be profitable for low-cost "innovating" firms to increase R&D expenditure and license the higher level of quality to a fewer number of high-cost "imitating" firms than would enter endogenously without licensing. Sutton's (1998) EFC model predicts that as the size of the market increases, existing firms escalate the levels of quality they offer rather than permit additional entry of new firms. This primary result of quality escalation continues to hold when we permit firms to license their technology to rivals, but low-cost innovators are able to increase the number of licenses to high-cost imitators as market size increases.

Regulators and policymakers will find these results particularly relevant as the announcements of license and cross-license agreements between firms within the same industry are often accompanied by concerns of collusion and anti-competitive behavior. As we have shown however, the ability of firms to license their technology increases the highest levels of quality offered by providing additional incentives to R&D for low-cost market leaders. Without an explicit expression of the functional form of the utility function, we are unable to determine the welfare effects of higher market concentration, accompanied by higher levels of R&D investment and product quality. Thus, the consumer welfare effects of an endogenous market structure and innovation under asymmetric R&D costs and licensing remains an open area for future research.

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Appendix A

Proof to Proposition 1 and Corollary to Proposition 1: In order to derive the first condition in Proposition 1, we compare the conditions on the feasible set of equilibrium as characterized by equations (20) and (21). As the left-hand side and fixed-cost term on the right-hand side are equivalent across equations, we can focus upon the relationship between $[1 + L^n \rho(\kappa\hat{v}')\gamma_n] S\pi(\kappa\hat{u}'|\mathbf{\acute{u}})$ and $S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}')$. The larger of these two terms will determine which of the stability conditions will be binding upon low-cost firms. As these relationships hold for all values of the escalation parameter $\kappa > 1$, we can derive an expression for the proportion of sales revenues accrued to innovating firms in licensing agreements. Specifically this depends upon:

$$\rho(\kappa\hat{v}) \gtreqless \frac{1}{L^n \gamma_n}\left[\frac{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}')}{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}})} - 1\right], \quad \forall \kappa > 1. \qquad (A.1)$$

The expression on the right-hand side of equation $(A.1)$ is non-negative for any positive rent dissipation effect. The rent dissipation effect falls directly out of the profit function such that equation $(A.1)$ implies the first licensor stability condition $(S.2')$ will bind over the second licensor stability condition $(S.2'')$ if the right-hand side is less than or equal to $\rho(\kappa\hat{v})$.

Without the assumption of either an explicit functional form on the per-consumer profit function or the nature of competition in the product market, we cannot determine if the rent dissipation effect will be large or small. However, we can make some inferences as to when each of these cases is likely to arise. If product market competition is intense such that the rent dissipation effect is large, we are likely to observe $\rho(\kappa\hat{v}) \leq \frac{1}{L^n \gamma_n}\left[\frac{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}')}{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}})} - 1\right]$ as $\rho(\kappa\hat{v})$ is bounded between 0 and 1. If the product market competition is not strong such that rent dissipation is weak, we are likely to find that the converse holds such that first licensor stability condition $(S.2')$ will be binding.

The first condition within the Corollary to Proposition 1 follows directly from the derivation for the corresponding condition within Proposition 1. Namely, if the second stability condition on licensor firms is to bind, then equation (21) specifies the feasible set of equilibrium configurations as the first term on the right-hand side is no less than the first right-hand side term in equation (20). We have found that this condition will be binding under intense product market competition and large rent dissipation effects.

The second part of Proposition 1 is derived by comparing condition (20) and (22). Assuming that market size and firm profits are sufficiently large relative to fixed cost expenditures along other trajectories and fixed transactions costs associated with licensing, comparing the coefficients on the first terms yields the following relationship:

$$\frac{1}{\kappa^{\beta^L}}\left[\frac{1+L^n\rho(\kappa\hat{v}')\gamma_n}{1+L^n\rho(\hat{v}')\gamma_n}\right] \gtreqless \frac{1}{\kappa^{\beta^H}}\left[\frac{1+L^n\rho(\kappa\hat{v}')\gamma_n}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\rho(\hat{v}')\gamma_n}\right], \quad \forall\kappa > 1. \qquad (A.2)$$

We can interpret the relationship specified in equation $(A.2)$ as follows. If the left-hand side is greater than or equal to the right-hand side, then the licensor viability and stability conditions provide a more restrictive set of feasible equilibrium configurations independently of fixed costs associated with R&D investment in other attributes or transactions costs associated with licensing. Similarly, if the right-hand side is greater than left-hand side, then the licensee viability and stability conditions provide the relevant constraints upon the feasible set of equilibrium. Simplifying yields the following condition on the proportion of sales revenues that licensees can earn for a given level of quality:

$$\rho(\hat{v}') \lesseqgtr \frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H} - \kappa^{\beta^L}}{\kappa^{\beta^L}L^n + \kappa^{\beta^H} - 1}\right], \quad \forall\kappa > 1. \qquad (A.3)$$

As we have assumed $\beta^H > \beta^L$, the right-hand side of this condition is nonnegative for all $\kappa > 1$. Thus, the set of equilibrium configurations derived from the licensor viability and stability conditions $(V.2')$ and $(S.2')$ will be the binding to the feasible set of equilibrium configurations if: $\rho(\hat{v}) \leq \frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H} - \kappa^{\beta^L}}{\kappa^{\beta^L}L^n + \kappa^{\beta^H} - 1}\right], \quad \forall\kappa > 1.$

In order to derive the second condition in the Corollary to Proposition 1, we compare equation (21) to equation (22) under the assumption that market size is sufficiently large or fixed R&D and transactions costs are sufficiently small. The relationship that we are interested in can be specified as:

$$\frac{1}{\kappa^{\beta^L}}\left[\frac{1}{1 + L^n\rho(\hat{v}')\gamma_n}\right]S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}') \gtreqless \frac{1}{\kappa^{\beta^H}}\left[\frac{1 + L^n\rho(\kappa\hat{v}')\gamma_n}{1 - \left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\rho(\hat{v}')\gamma_n}\right]S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}), \quad \forall\kappa > 1. \qquad (A.4)$$

Re-arranging:

$$\left[1 - \left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\rho(\hat{v}')\gamma_n\right]\frac{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}')}{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}})} \gtreqless \frac{\kappa^{\beta^L}}{\kappa^{\beta^H}}[1 + L^n\rho(\kappa\hat{v}')\gamma_n][1 + L^n\rho(\hat{v}')\gamma_n], \quad \forall\kappa > 1. \qquad (A.5)$$

As we have already determined that $\rho(\kappa\hat{v}') \leq \frac{1}{L^n\gamma_n}\left[\frac{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}')}{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}})} - 1\right]$ for condition (21) to provide the binding set of feasible equilibrium configurations, we know that the right-hand side of expression $(A.5)$ will be greatest for $\rho(\kappa\hat{v}') = \frac{1}{L^n\gamma_n}\left[\frac{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}')}{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}})} - 1\right]$. Substituting and simplifying yields:

$$\rho(\hat{v}') \lesseqgtr \frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H} - \kappa^{\beta^L}}{\kappa^{\beta^L}L^n + \kappa^{\beta^H} - 1}\right], \quad \forall\kappa > 1. \qquad (A.6)$$

As was the case for Proposition 1, the set of equilibrium configurations derived from the licensor viability and stability conditions $(V.2')$ and $(S.2'')$ will be the binding to the feasible set of equilibrium configurations if: $\rho(\hat{v}) \leq \frac{1}{\gamma n}\left[\frac{\kappa^{\beta^H}-\kappa^{\beta^L}}{\kappa^{\beta^L}L^n+\kappa^{\beta^H}-1}\right], \quad \forall\kappa > 1.$ ■

Appendix B

Proof of Proposition 2: Consider some equilibrium configuration $\mathbf{u}$ without licensing in which the market-leading firm produces maximum quality $\hat{u}$ by attaining maximum competency $\hat{v}$ along some trajectory n while producing an "industry standard" level of competency across all other trajectories. Let the sales revenue from the associated products be denoted $S\hat{r}$ such that its share of industry sales revenue is $S\hat{r}/Sr(\mathbf{u})$. Suppose the high-spending, low-cost entrant produces quality $\kappa\hat{u}$ by attaining capability $\kappa\hat{v}$ along trajectory n and achieves the "industry standard" level of competency across all other trajectories.[5] By definition of $a(\kappa)$, the high-spending entrant obtains a profit net of sunk costs of at least: $a(\kappa)Sr(\mathbf{u}) - F^L(\kappa\hat{v}) - \sum_{m\neq n} F^L(\overline{v}_m)$.

Recall that the relevant stability condition $(S.1)$ implies that the profit of an escalating entrant is non-positive such that:

$$F^L(\hat{v}) \geq \frac{a(\kappa)}{\kappa^{\beta^L}} Sr(\mathbf{u}) - \frac{1}{\kappa^{\beta^L}} \sum_{m\neq n} F^L(\overline{v}_m)\,, \quad \kappa \geq 1. \qquad (B.1)$$

The viability condition $(V.1)$ necessitates the current market-leader in quality has profits that cover its fixed outlays. Thus, regardless of the marginal costs of production (assumed to be zero here for simplicity and congruency with subsequent results), the sales and licensing revenue of the market-leading firm must at least be as large as its sunk R&D expenditures which implies:

$$S\hat{r} - \sum_{m\neq n} F^L(\overline{v}_m) \geq F^L(\hat{v}). \qquad (B.2)$$

Combining these conditions yields:

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[5] The assumption that there is an "industry standard" level of quality offered on all other trajectories is consistent with the results of Irmen and Thisse (1998). They show that maximum differentiation along a single characteristic, and minimum differentiation across all other characteristics, is sufficient to relax price competition, regardless of whether there exists a "dominant" attribute or all attributes are weighted evenly.

$$S\hat{r} - \sum_{m\neq n} F^L(\overline{v}_m) \geq F^L(\hat{v}) \geq \frac{a(\kappa)}{\kappa^{\beta^L}} Sr(\mathbf{u}) - \frac{1}{\kappa^{\beta^L}} \sum_{m\neq n} F^L(\overline{v}_m), \quad \kappa \geq 1. \qquad (B.3)$$

Therefore, the market share of sales along the highest-quality trajectory is:

$$\frac{S\hat{r}}{Sr(\mathbf{u})} \geq \frac{a(\kappa)}{\kappa^{\beta^L}} + \left(\frac{\kappa^{\beta^L} - 1}{\kappa^{\beta^L}}\right)\left[\frac{\sum_{m\neq n} F^L(\overline{v}_m)}{Sr(\mathbf{u})}\right]. \qquad (B.4)$$

Condition $(B.4)$ implies that as the market size becomes large (i.e. $S \to \infty$), the second term approaches zero and the market share of the quality-leading firm is bounded away from zero by $\frac{a(\kappa)}{\kappa^{\beta^L}}$. ■

Proof of Proposition 3: We consider the case of a high-spending entrant that achieves competency $\kappa\hat{v}'$ along some trajectory n (with overall quality of $\kappa\hat{u}'$) and licenses this competency to high-cost rivals. Let the current market leader produce quality $\hat{u}'$ by achieving competency $\hat{v}'$ along trajectory n, earn sales revenue of the market leader as $S\hat{r}'$, and achieve a share of the industry sales revenue equal to $S\hat{r}'/Sr(\acute{\mathbf{u}})$. By definition of $\acute{a}(\kappa)$, the high-spending entrant obtains a profit with licensing revenue net of sunk costs of at least: $\acute{a}(\kappa)Sr(\acute{\mathbf{u}}) - F^L(\kappa\hat{v}') - \sum_{m\neq n} F^L(\overline{v}_m) + L^n\gamma_n\rho(\kappa\hat{v}')\acute{a}(\kappa)Sr(\acute{\mathbf{u}})$.

The stability condition $(S.2')$ for licensor firms implies that the profit of an escalating entrant is non-positive such that:

$$F^L(\hat{v}') \geq \frac{\acute{a}(\kappa)}{\kappa^{\beta^L}}[1 + L^n\gamma_n\rho(\kappa\hat{v}')]Sr(\acute{\mathbf{u}}) - \frac{1}{\kappa^{\beta^L}} \sum_{m\neq n} F^L(\overline{v}_m), \quad \kappa \geq 1. \qquad (B.5)$$

Moreover, the relevant viability condition $(V.2')$ implies that the current quality leader that licenses its competency to rivals has profits and licensing revenues that are greater than its fixed R&D costs. Again assuming that marginal costs of production are zero, the viability condition can be specified as:

$$[1 + L^n \gamma_n \rho(\hat{v}')] S\hat{r}' - \sum_{m \neq n} F^L(\overline{v}_m) \geq F^L(\hat{v}'). \qquad (B.6)$$

Combining equations $(B.5)$ and $(B.6)$ and simplifying yields:

$$[1 + L^n \gamma_n \rho(\hat{v}')] S\hat{r}' \geq \frac{\acute{a}(\kappa)}{\kappa^{\beta^L}} [1 + L^n \gamma_n \rho(\kappa \hat{v}')] Sr(\mathbf{\acute{u}}) + \left(\frac{\kappa^{\beta^L} - 1}{\kappa^{\beta^L}} \right) \sum_{m \neq n} F^L(\overline{v}_m), \kappa \geq 1. \quad (B.7)$$

The market share of sales for firm producing the highest level of quality and licensing its competency to high-cost rivals can be expressed as:

$$\frac{S\hat{r}'}{Sr(\mathbf{\acute{u}})} \geq \frac{\acute{a}(\kappa)}{\kappa^{\beta^L}} \cdot \left[\frac{1 + L^n \gamma_n \rho(\kappa \hat{v}')}{1 + L^n \gamma_n \rho(\hat{v}')} \right] + \left(\frac{\kappa^{\beta^L} - 1}{\kappa^{\beta^L}} \right) \left[\frac{\sum_{m \neq n} F^L(\overline{v}_m)}{[1 + L^n \gamma_n \rho(\hat{v}')] Sr(\mathbf{\acute{u}})} \right]. \qquad (B.8)$$

As the size of the market becomes large, the second term in equation $(B.8)$ approaches zero and the lower bound to market concentration derived from the equilibrium conditions for licensor firms is: $\frac{\acute{a}(\kappa)}{\kappa^{\beta^L}} \cdot \left[\frac{1 + L^n \gamma_n \rho(\kappa \hat{v}')}{1 + L^n \gamma_n \rho(\hat{v}')} \right]$. ∎

Proof of Corollary to Proposition 3: We consider the case of a high-spending entrant that achieves competency $\kappa \hat{v}'$ along some trajectory n (with overall quality of $\kappa \hat{u}'$) but does not license this competency to high-cost rivals. Let the current market leader produce quality $\hat{u}'$ by achieving competency $\hat{v}'$ along trajectory n, earn sales revenue of the market leader as $S\hat{r}'$, and achieve a share of the industry sales revenue equal to $S\hat{r}'/Sr(\mathbf{\acute{u}})$. By definition of $\acute{a}(\kappa)$, the high-spending entrant obtains a profit net of sunk costs without licensing revenue of at least: $\acute{a}(\kappa) \varphi Sr(\mathbf{\acute{u}}) - F^L(\kappa \hat{v}') - \sum_{m \neq n} F^L(\overline{v}_m)$. The constant $\varphi \geq 1$ captures the increased revenue that the entrant earns by not licensing its technology and thus avoiding the rent dissipation effect of technology licensing.

The stability condition $(S.2'')$ for licensor firms implies that the profit of an escalating entrant is non-positive such that:

$$F^L(\hat{v}') \geq \frac{\acute{a}(\kappa)}{\kappa^{\beta^L}}\varphi Sr(\acute{\mathbf{u}}) - \frac{1}{\kappa^{\beta^L}}\sum_{m\neq n} F^L(\overline{v}_m), \quad \kappa \geq 1. \qquad (B.9)$$

Moreover, the relevant viability condition $(V.2')$ implies that the current quality leader that licenses its competency to rivals has profits and licensing revenues that are greater than its fixed R&D costs. Again assuming that marginal costs of production are zero, the viability condition can be specified as:

$$[1 + L^n\gamma_n\rho(\hat{v}')]S\hat{r}' - \sum_{m\neq n} F^L(\overline{v}_m) \geq F^L(\hat{v}'). \qquad (B.10)$$

Combining equations $(B.9)$ and $(B.10)$ and simplifying yields:

$$[1 + L^n\gamma_n\rho(\hat{v}')]S\hat{r}' \geq \frac{\acute{a}(\kappa)}{\kappa^{\beta^L}}\varphi Sr(\acute{\mathbf{u}}) + \left(\frac{\kappa^{\beta^L} - 1}{\kappa^{\beta^L}}\right)\sum_{m\neq n} F^L(\overline{v}_m), \kappa \geq 1. \qquad (B.11)$$

The market share of sales for firm producing the highest level of quality and licensing its competency to high-cost rivals can be expressed as:

$$\frac{S\hat{r}'}{Sr(\acute{\mathbf{u}})} \geq \frac{\acute{a}(\kappa)}{\kappa^{\beta^L}} \cdot \left[\frac{\varphi}{1 + L^n\gamma_n\rho(\hat{v}')}\right] + \left(\frac{\kappa^{\beta^L} - 1}{\kappa^{\beta^L}}\right)\left[\frac{\sum_{m\neq n} F^L(\overline{v}_m)}{[1 + L^n\gamma_n\rho(\hat{v}')]Sr(\acute{\mathbf{u}})}\right]. \qquad (B.12)$$

As the size of the market becomes large, the second term in equation (42) approaches zero and the lower bound to market concentration derived from the equilibrium conditions for licensor firms is: $\frac{\acute{a}(\kappa)}{\kappa^{\beta^L}} \cdot \left[\frac{\varphi}{1+L^n\gamma_n\rho(\hat{v}')}\right]$. ■

Proof of Proposition 4: Now we consider the case of a high-spending entrant that licenses competence $\hat{v}'$ from the market leader and then escalates its competence by a factor $\kappa > 1$ to attain an overall quality level of $\kappa\hat{u}'$. From the definition of $\acute{a}(\kappa)$, we can specify the profits net of sunk costs and transactions costs associated with licensing for this firm as being greater than or equal to: $\acute{a}(\kappa)Sr(\mathbf{\acute{u}}) - \gamma_n\rho(\hat{v}')S\hat{r}' + +L^n\gamma_n\rho(\kappa\hat{v}')\acute{a}(\kappa)Sr(\mathbf{\acute{u}}) - \left[1-(1-\delta)^{\beta^H}\right]F^H(\kappa\hat{v}') - \sum_{m\neq n}F^H(\overline{v}_m) - T_0$.

From the stability condition for licensee firms $(S.3'')$, the profit of an escalating entrant that licenses competency $\hat{v}$ from the market leader and then licenses its escalated competency to rivals is non-positive such that:

$$\left[1-(1-\delta)^{\beta^H}\right]F^H(\hat{v}') \geq \frac{\acute{a}(\kappa)}{\kappa^{\beta^H}}[1+L^n\gamma_n\rho(\kappa\hat{v}')]Sr(\mathbf{\acute{u}}) - \frac{\gamma_n\rho(\hat{v}')}{\kappa^{\beta^H}}S\hat{r}' - \frac{1}{\kappa^{\beta^H}}\left[\sum_{m\neq n}F^H(\overline{v}_m) - T_0\right], \quad \kappa \geq 1. \qquad (B.13)$$

The viability condition for licensee firms $(V.3')$ implies that a licensee of the market-leading competency $\hat{v}'$ earns profits that are greater than both the "catch-up" R&D from the imperfect transfer of technologies across firms and the transactions costs associated with the license T_0. Therefore, sales revenue of the licensee firm is such that:

$$[1-\rho(\hat{v}')\gamma_n]S\hat{r}' - \sum_{m\neq n}F^H(\overline{v}_m) - T_0 \geq \left[1-(1-\delta)^{\beta^H}\right]F^H(\hat{v}'). \qquad (B.14)$$

Combining the conditions $(B.13)$ and $(B.14)$ yields the expression:

$$\left[1-\rho(\hat{v}')\gamma_n + \frac{\gamma_n\rho(\hat{v}')}{\kappa^{\beta^H}}\right]S\hat{r}' \geq \frac{\acute{a}(\kappa)}{\kappa^{\beta^H}}[1+L^n\gamma_n\rho(\kappa\hat{v}')]Sr(\mathbf{\acute{u}}) + \left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\left[\sum_{m\neq n}F^H(\overline{v}_m) + T_0\right], \quad \kappa \geq 1. \qquad (B.15)$$

Therefore, the market share of any firm producing the market-leading level of quality and the maximum competency $\hat{v}'$ in equilibrium must satisfy:

$$\frac{S\hat{r}'}{Sr(\mathbf{ú})} \geq \frac{á(\kappa)}{\kappa^{\beta^H}} \cdot \left[\frac{1 + L^n \gamma_n \rho(\kappa \hat{v}')}{1 - \left(\frac{\kappa^{\beta^H} - 1}{\kappa^{\beta^H}}\right) \gamma_n \rho(\hat{v}')}\right] + \left(\frac{\kappa^{\beta^H} - 1}{\kappa^{\beta^H}}\right) \left[\frac{\sum_{m \neq n} F^H(\overline{v}_m) + T_0}{\left[1 - \left(\frac{\kappa^{\beta^H} - 1}{\kappa^{\beta^H}}\right) \gamma_n \rho(\hat{v}')\right] Sr(\mathbf{ú})}\right]. \quad (B.16)$$

As the size of the market becomes large, the second term approaches zero and the lower bound to concentration as derived from the equilibrium conditions on licensee firms is: $\frac{á(\kappa)}{\kappa^{\beta^H}} \cdot \left[\frac{1 + L^n \gamma_n \rho(\kappa \hat{v}')}{1 - \left(\frac{\kappa^{\beta^H} - 1}{\kappa^{\beta^H}}\right) \gamma_n \rho(\hat{v}')}\right]$. ■

Appendix C

Proof of Theorem 1: (Proof by Transposition) Prior to commencing the proof, it is useful to recall the three conditions (20)-(22) that we specified in order to determine which viability and stability conditions characterized the feasible set of equilibrium configurations. The two licensor conditions can be expressed as:

$$S\pi(\hat{u}'|\acute{\mathbf{u}}) \geq \tfrac{1}{\kappa^{\beta^L}}\left[\frac{1+L^n\rho(\kappa\hat{v}')\gamma_n}{1+L^n\rho(\hat{v}')\gamma_n}\right]S\pi(\kappa\hat{u}'|\acute{\mathbf{u}}) + \left(\tfrac{\kappa^{\beta^L}-1}{\kappa^{\beta^L}}\right)\left[\frac{\sum_{m\neq n}F^L(v_m)}{1+L^n\rho(\hat{v}')\gamma_n}\right] \tag{20}$$

$$S\pi(\hat{u}'|\acute{\mathbf{u}}) \geq \tfrac{1}{\kappa^{\beta^L}}\left[\frac{1}{1+L^n\rho(\hat{v}')\gamma_n}\right]S\pi(\kappa\hat{u}'|\acute{\mathbf{u}}') + \left(\tfrac{\kappa^{\beta^L}-1}{\kappa^{\beta^L}}\right)\left[\frac{\sum_{m\neq n}F^L(v_m)}{1+L^n\rho(\hat{v}')\gamma_n}\right] \tag{21}$$

whereas the licensee condition can be expressed as:

$$S\pi(\hat{u}'|\acute{\mathbf{u}}) \geq \tfrac{1}{\kappa^{\beta^H}}\left[\frac{1+L^n\rho(\kappa\hat{v}')\gamma_n}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\rho(\hat{v}')\gamma_n}\right]S\pi(\kappa\hat{u}'|\acute{\mathbf{u}}) + \left(\tfrac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\left[\frac{\sum_{m\neq n}F^H(v_m)+T_0}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\rho(\hat{v}')\gamma_n}\right]. \tag{22}$$

Suppose that the licensee viability $(V.3')$ and stability $(S.3'')$ conditions are not the relevant conditions in defining equilibrium configurations implying that equation (22) does not bind the feasible set of configurations. If equilibrium configurations are not determined by the licensee conditions, then they must be determined by the licensor viability $(V.2')$ condition and one of the licensor stability $(S.2', S.2'')$ conditions, hence either equation (20) or (21).

First, consider the case in which a quality-escalating entrant also licenses its technology to rivals such that equation (20) is binding. If equation (20) provides the relevant condition on the binding set of equilibrium configurations, then it must be that for sufficiently large markets, the right-hand side of (20) is greater than the right-hand side of (22). Specifically,

$$\frac{1}{\kappa^{\beta^L}}\left[\frac{1+L^n\rho(\kappa\hat{v}')\gamma_n}{1+L^n\rho(\hat{v}')\gamma_n}\right]S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}) > \frac{1}{\kappa^{\beta^H}}\left[\frac{1+L^n\rho(\kappa\hat{v}')\gamma_n}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\rho(\hat{v}')\gamma_n}\right]S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}). \qquad (C.1)$$

Simplifying equation $(C.1)$ yields the following expression in which the licensee conditions are not binding:

$$\rho(\hat{v}') < \frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H}-\kappa^{\beta^L}}{\kappa^{\beta^L}L^n+\kappa^{\beta^H}-1}\right], \quad \forall\kappa > 1. \qquad (C.2)$$

Now considering the case in which a quality-escalating entrant does not license its technology to rivals, equation (21) will define the binding set of feasible equilibrium configurations. The equivalent expression to equation $(C.1)$ assuming sufficiently-sized markets can be specified as:

$$\frac{1}{\kappa^{\beta^L}}\left[\frac{1}{1+L^n\rho(\hat{v}')\gamma_n}\right]S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}') > \frac{1}{\kappa^{\beta^H}}\left[\frac{1+L^n\rho(\kappa\hat{v}')\gamma_n}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\rho(\hat{v}')\gamma_n}\right]S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}). \qquad (C.3)$$

Dividing both sides by $S\pi(\kappa\hat{u}'|\mathbf{\acute{u}})$ and re-arranging yields the expression:

$$\frac{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}')}{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}})} > \kappa^{\beta^L}\left[\frac{[1+L^n\rho(\kappa\hat{v}')\gamma_n][1+L^n\rho(\hat{v}')\gamma_n]}{\kappa^{\beta^H}-\left(\kappa^{\beta^H}-1\right)\rho(\hat{v}')\gamma_n}\right]. \qquad (C.4)$$

In the Corollary to Proposition 1, we determined that in order for equation (21) to be binding relative to equation (20), it must be that: $\rho(\kappa\hat{v}') \leq \frac{1}{L^n\gamma_n}\left[\frac{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}')}{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}})}-1\right]$. Thus, the right-hand side of equation (50) is no less than: $\kappa^{\beta^L}\left[\frac{1+L^n\rho(\hat{v}')\gamma_n}{\kappa^{\beta^H}-\left(\kappa^{\beta^H}-1\right)\rho(\hat{v}')\gamma_n}\right]\frac{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}}')}{S\pi(\kappa\hat{u}'|\mathbf{\acute{u}})}$.

Simplifying and re-arranging yields the following expression in which the licensee conditions are not binding:

$$\rho(\hat{v}') < \frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H}-\kappa^{\beta^L}}{\kappa^{\beta^L}L^n+\kappa^{\beta^H}-1}\right], \quad \forall\kappa > 1. \qquad (C.5)$$

If the licensee viability and stability conditions are not binding in the definition of the feasible set of equilibrium configurations, it must be $\rho(\hat{v}') < \frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H}-\kappa^{\beta^L}}{\kappa^{\beta^L}L^n+\kappa^{\beta^H}-1}\right]$ regardless of which licensor conditions are specified. This is the contra positive to Theorem 1 implying that if $\rho(\hat{v}') \geq \frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H}-\kappa^{\beta^L}}{\kappa^{\beta^L}L^n+\kappa^{\beta^H}-1}\right]$, it must be that equation (22) defines the binding set of feasible equilibrium configurations. Moreover, from Proposition 4 we derived the lower bound to market concentration from the licensee viability and stability conditions. As these conditions determine the most restricted set of feasible equilibrium configurations, we can determine that the market share of any firm producing the market-leading level of quality and the maximum competency $\hat{v}'$ in equilibrium must satisfy:

$$\frac{S\hat{r}'}{Sr(\acute{\mathbf{u}})} \geq \frac{\acute{a}(\kappa)}{\kappa^{\beta^H}} \cdot \left[\frac{1+L^n\gamma_n\rho(\kappa\hat{v}')}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\gamma_n\rho(\hat{v}')}\right] + \left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\left[\frac{\sum_{m\neq n} F^H(\overline{v}_m)+T_0}{\left[1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\gamma_n\rho(\hat{v}')\right]Sr(\acute{\mathbf{u}})}\right]. \qquad (C.6)$$

As the size of the market becomes large, the second term approaches zero and the lower bound to concentration as derived from the equilibrium conditions on licensee firms is: $\frac{\acute{a}(\kappa)}{\kappa^{\beta^H}} \cdot \left[\frac{1+L^n\gamma_n\rho(\kappa\hat{v}')}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\gamma_n\rho(\hat{v}')}\right]$. ■

Proof of Corollary to Theorem 1: Under sufficiently large market size, equation (46) embeds Sutton's lower bound to concentration without licensing, namely $\frac{S\hat{r}}{Sr(\mathbf{u})} \geq \frac{\acute{a}(\kappa)}{\kappa^{\beta^H}}$, by setting the total number of licensee firms and the fixed-fee royalty payment equal to zero (i.e. $L^n = 0$ and $\rho(\hat{u}') = 0$). From Proposition 2, we observe that the lower bound when products are characterized by multiple attributes is greater than the non-convergent lower bound found by Sutton (1998). Moreover, we observe that the lower bound to the market share of quality leaders are strictly decreasing in market size and are least when market size becomes large (i.e. $S \to \infty$). Thus, whereas Sutton found a non-convergent lower bound that was independent of the size of the market, the presence of multiple product attributes and transactions costs associated with licensing implies that the lower bound to concentration is not independent from the size of the market, but converges to a positive lower bound as the size of the market increases.

Sutton's lower bound under multiple attribute products and markets of sufficiently large size can be specified as $\frac{a(\kappa)}{\kappa^{\beta^L}}$ whereas the lower bound under licensing can be specified as $\frac{\acute{a}(\kappa)}{\kappa^{\beta^H}} \cdot \left[\frac{1+L^n\gamma_n\rho(\kappa\hat{v}\prime)}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\gamma_n\rho(\hat{v}\prime)}\right]$. We make two simplifying assumption in order to characterize the lower bound under licensing as greater than the bound Sutton's bound. First, we assume that the minimum ratio of firm profit to industry sales for all κ is equivalent with $a(\kappa)$ and without licensing $\acute{a}(\kappa)$. Second, we assume that the fixed-fee royalty payment is constant such that $\rho(\kappa\hat{v}') = \rho(\hat{v}') = \rho$. The greater lower bound depends upon the following relationship:

$$\frac{1}{\kappa^{\beta^L}} \gtreqless \frac{1}{\kappa^{\beta^H}} \cdot \left[\frac{1+L^n\gamma_n\rho}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\gamma_n\rho}\right]. \qquad (C.7)$$

Re-arranging yields:

$$\frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H}-\kappa^{\beta^L}}{\kappa^{\beta^L}L^n+\kappa^{\beta^H}-1}\right] \gtreqless \rho. \qquad (C.8)$$

If the licensee viability and stability conditions continue to bind the feasible set of equilibrium configurations under licensing, then $\rho \geq \frac{1}{\gamma_n}\left[\frac{\kappa^{\beta^H}-\kappa^{\beta^L}}{\kappa^{\beta^L}L^n+\kappa^{\beta^H}-1}\right]$ such that there is a greater lower bound under licensing. ■

Proof of Theorem 2: Consider the quality-escalating entrant's profit derived from the licensor stability condition $(S.2')$ is at least:

$$\begin{aligned}&[1+L^n\gamma_n\rho(\kappa\hat{v}')]\acute{a}(\kappa)Sr(\mathbf{\acute{u}})-\kappa^{\beta^L}F^L(\hat{v}')-(n_i-1)F_0\\ &\quad=[1+L^n\gamma_n\rho(\kappa\hat{v}')]\acute{a}(\kappa)Sr(\mathbf{\acute{u}})-\kappa^{\beta^L}D^L(\hat{v}')-\left(n_i+\left(\kappa^{\beta^L}-1\right)\right)F_0,\end{aligned} \qquad (C.9)$$

where n_i is the total number of research trajectories pursued by the innovating quality leader. The R&D spending of the low-cost quality leader is at least $D^L(\hat{v}')$ and it earns sales revenue, separate from licensing revenue, equal to $S\hat{r}'$ such that the R&D/sales ratio must be at least $D^L(\hat{v}')/S\hat{r}'$. We substitute for R&D costs in equation $(C.9)$ according to:

$$D^L(\hat{v}')=\frac{D^L(\hat{v}')}{S\hat{r}'}\cdot S\hat{r}'\leq\frac{D^L(\hat{v}')}{S\hat{r}'}\cdot Sr(\mathbf{\acute{u}}). \qquad (C.10)$$

Thus, combining inequality $(C.10)$ with equation $(C.9)$ yields an expression for the entrant's net profit such that:

$$[1+L^n\gamma_n\rho(\kappa\hat{v}')]\acute{a}(\kappa)Sr(\mathbf{\acute{u}})-\kappa^{\beta^L}\frac{D^L(\hat{v}')}{S\hat{r}'}\cdot Sr(\mathbf{\acute{u}})-\left(n_i+\left(\kappa^{\beta^L}-1\right)\right)F_0. \qquad (C.11)$$

The licensor stability condition $(S.2')$ implies that equation $(C.11)$ is non-positive. Re-arranging yields the expression:

$$\frac{D^L(\hat{v}')}{S\hat{r}'}\geq\frac{\acute{a}(\kappa)}{\kappa^{\beta^L}}[1+L^n\gamma_n\rho(\kappa\hat{v}')]-\frac{\left(n_i+\left(\kappa^{\beta^L}-1\right)\right)F_0}{\kappa^{\beta^L}Sr(\mathbf{\acute{u}})}. \qquad (C.12)$$

From the analysis on the concentration ratios, we observed that the sales of the market leader in quality is at least $\frac{\acute{\alpha}(\kappa)}{\kappa^{\beta^H}} \cdot \left[\frac{1+L^n\gamma_n\rho(\kappa\hat{v}\prime)}{1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\gamma_n\rho(\hat{v}\prime)}\right]$, $\forall\kappa > 1$. Thus, we can compare the coefficient of the first term in expression $(C.12)$ in order to determine if we would expect the lower bound to R&D/sales ratio of the quality leader is greater than, equal to, or less than the lower bound on market concentration. By inspection, the lower bound on R&D/sales ratio is greater than the lower bound to market concentration. Substituting for $\acute{\alpha}$:

$$\frac{D^L(\hat{v}')}{S\hat{r}'} \geq \acute{\alpha}\kappa^{\beta^H-\beta^L} \left[1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\gamma_n\rho(\hat{v}')\right] - \frac{\left(n_i+\left(\kappa^{\beta^L}-1\right)\right)F_0}{\kappa^{\beta^L}Sr(\mathbf{\acute{u}})}. \qquad (C.13)$$

Thus, as the market size becomes large, the R&D/sales ratio is bounded from below by $\acute{\alpha}\kappa^{\beta^H-\beta^L} \left[1-\left(\frac{\kappa^{\beta^H}-1}{\kappa^{\beta^H}}\right)\gamma_n\rho(\hat{v}')\right], \forall\kappa > 1$. Under the assumptions over the fixed-fee royalty payment, $\kappa > 1$, and $\beta^H > \beta^L > 2$, the lower bound to the R&D/sales ratio is strictly greater than the lower bound to market concentration in sales.■